National Science Challenges

OUR LAND AND WATER

Toitū te Whenua, Toiora te Wai

Protein Futures: Future Scenarios for Land-Use in Aotearoa New Zealand

Synthesis Report

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Executive Summary

The Protein Futures NZ project was designed to provide insight to the potential implications of alternative proteins (including plant-based, fermentation and cellular) on land use change and environment outcomes in Aotearoa/New Zealand. International academic literature and investment trends, as discussed in this report, indicate that alternative proteins have the potential to impact the global protein market by increasing the supply of available protein sources,. They also claim to offer environmental and animal welfare benefits over traditional animal-based proteins. While the extent and speed at which alternative protein value chains develop is uncertain, any increase in supply from these sources is likely to impact the export of proteins. As part of the project, economic and land use modelling were used to assess the potential scope of change, and the results were presented to knowledgeable stakeholders. The results and feedback from the stakeholders indicate the need for policy or strategy that addresses the impact of alternative proteins on Aotearoa/New Zealand's primary sector.

Insights from media and literature

It is apparent in media reporting and academic literature that alternative proteins have attracted significant attention as both an emerging contributor to global protein supplies and the focus of significant private investment. Internationally, alternative proteins are presented in promissory terms. Despite the relatively low level of current production, they are seen as a more sustainable solution for meeting the nutritional demands of a growing global population through to 2050. While these projections deserve to be viewed with some scepticism, it is important to acknowledge the level of interest, the potential for scientific advance and technological development for these proteins.

The media representations in Aotearoa/New Zealand share some of the promissory elements that are present internationally, while also considering potential competition with traditional animal proteins. Here, the focus is on start-ups such as Leaft Foods, the potential for oat milk or early progress at research institutions including the Riddet Institute. There is also, however, significant levels of scepticism regarding the potential for alternative proteins to replace those from the dairy or meat sectors. The range of perspectives on and assessments of the potential of alternative proteins is echoed by experts interviewed for the project.

Scenarios for alternative protein development

To best account for the lack of certain futures for alternative proteins, the Protein Futures NZ project developed a set of four scenarios to inform the modelling of economic and environmental impacts for Aotearoa/New Zealand (see Table 1). The parameters for the growth of alternative proteins in each scenario is based on published projections that are developed by investment consultants or academic experts (see the full report for details).

The first scenario provides a 'Baseline', which used a conservative projection of alternative protein growth consistent with current trends (including a negligible contribution from cellular meats to reflect the current lack of commercial scale production outside of GOOD Meat chicken in Singapore). While not a highly likely outcome given the level of interest and investment as well as recent technological advances associated with alternative proteins, this scenario provides a point of comparison for the impact of increasing production of alternative proteins on traditional value chains.

The second scenario considers a context in which there is moderately higher growth in plant-based and precision fermentation proteins, both of which are expected to impact on dairy, and

the protein ingredients derived from milk. This scenario further limits direct impacts on meat proteins by including moderate focus on environmental issues for consumers.

The third scenario focuses more exclusively on potential competitive pressures for meat proteins, with strong growth of plant-based proteins and some growth in cellular meats as direct replacements for animal-produced meat. This scenario also projects the reduction of constraints (including technological, regulatory and consumer perception) on the growth of alternative proteins.

The final scenario accounts for the most optimistic (yet still realistic) published projections for alternative proteins. This scenario assumes that technological, commercial, regulatory and consumer preference constraints are all largely overcome. While also a less likely scenario, It provides some insight to the highest level of impact for Aotearoa/New Zealand's protein value chains.

Table 1: Protein Futures summaries of Scenarios

Scenario 1	Scenario 2	Scenario 3	Scenario 4
• Reflects the current situation of increased demand in alternative proteins. • New emerging proteins contribute towards increased demand without significantly affecting traditional protein supply chains.	• Increase in demand for emerging proteins — Plant Proteins +10% and Precision Fermentation +22%. • Demand for emerging protein continues however technical issues stall the development of lab based (cultivated) protein products. • Sustainability is a key factor driving consumer acceptance and demand.	• Increase in demand for emerging proteins — Plant Protein +22%, Precision Fermentation +10% and Lab-based (Cultivated) +10%. • Plant-based protein products take off. • Sustainability is a key driver of consumer acceptance and demand.	• Increase in demand for emerging proteins — Plant Proteins +22%, Precision Fermentation +22% and Lab-based (Cultivated) +22%. • All current barriers to the success of alternative markets have been removed or are in the process of being overcome. • Scale of production has increased whilst regulation and market access barriers/tariffs for food are based on GHG emissions and other environmental outcomes.

Findings from modelling

The economic modelling consisted of a staged process to first project the impacts of alternative protein taking up a larger proportion of the substitutable global protein markets (Lincoln Trade and Environment Model) and then to estimate the domestic environmental and land use impacts associated with scenarios which represents New Zealand entering into the supply of alternative proteins (regional land use modelling) on a regional basis across New Zealand.

The LTEM modeling shows us that the price, supply, demand and net trade effects of trade and domestic agricultural support policies have the impact of diminishing the economic indicators at a National level as the percentage of the substitutable protein market taken up by alternative

proteins rises from 10 % up to 22% while the environmental indicators all fall substantially as the percentage rises.

What we can conclude from the LTEM modelling is that a small percentage of the substitutable protein market taken up by alternative proteins will have a negative effect on the National economic indicators while having a positive effect on the environmental indicators.

What we believe is the key message from the LTEM modelling is that New Zealand production of proteins will not be immune from the negative effects of alternative proteins taking up a proportion of the substitutable proteins market and that the negative impact will be quite significant for all of the economic indicators. This means that New Zealand must develop a strategy that has us participating in the global alternative proteins market if we want to continue to grow our GDP while at the same time improving our nutrient loss and greenhouse gas emissions performance.

In addition to the global trade modelling, a regional level model of land-use change was developed for the project which was able to model the impact of a range of possible scenarios where New Zealand joining in the production of alternative proteins on the International trade in alternative proteins has an impact on the current land use in New Zealand and some responses in terms of New Zealand joining into the production of alternative proteins. The range of scenarios and the impact of them on the National land use mix can be seen in Table 2.

Table 2: Scenario 1 National land uses and changes that occur as a result of the assumptions made across the remaining three Scenarios.

	Scenario 1 No impact on current land	**Scenario 2** Precision fermentation for dairy ingredients becomes competitive	**Scenario 3** Plant-based products take off	**Scenario 4** Emerging proteins take off
Sheep	4,136,872	-123,597	-620,531	-1,219,613
Beef	2,692,132	601,632	-216,604	-133,199
Dairy	2,072,083	-725,229	-310,812	-725,229
Arable	494,387	247,194	494,387	370,790
Hort & Vegetable	126,329	0	0	0
Forestry	1,619,010	0	653,560	1,707,251
Total	**11,140,813**			

The results of the modeling of the scenarios expressed at a National level can be seen in Table 3.

Table 3: The changes that occur in the output measures for each scenario compared with Scenario 1.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	No impact on current land	Precision fermentation for dairy ingredients becomes competitive	Plant-based products take off	Emerging proteins take off
Gross Output ($m)	43,489	-4,007	2,457	1,366
Total Change for NZ economy ($m)	99,282	-7,994	6,951	6,727
Employment (FTE)	321,924	-22,584	22,486	18,410
Value Added ($m)	46,765	-4,267	2,616	1,771
GHG Emissions (000 t CO2 e)	42,836	-5,615	-5,480	-11,999
N Loss (t)	193429	-11,427	-9,800	-33,451
P Loss (t)	15,427	-276	-736	-2,725

In summary we can conclude that the impact of a substantial change in the National involvement in alternative proteins will be positive for the economic indicators and spectacularly positive for the environmental indicators.

However it should be noted that this modeling only incorporates the financial impact at the farm gate level. It hasn't considered the transition costs like the potential large losses in capital which will result from the change from a particular land use to another land use which has different infrastructural requirements nor the loss of value of the processing and servicing sectors of those land use sectors.

The regional land use results are particularly variable with some having large losses in terms of the economic indicators while having positive results in terms of the environmental indicators while other regions have significant gains in both economic and environmental indicators.

These results reflect the greater sensitivity of the regional land-use modelling to the financial impacts of changes in production systems. It is also notable that the land-use potential of the regions impacts significantly on response to a larger increase in the contribution of alternative proteins to the global economy. This regional variation raises important issues for consideration of policy responses.

Relevance for policy

On their own, the modelling results are an interesting academic and theoretical finding. To better understand the perceived implications of these results for Aotearoa/New Zealand's primary sector, the Protein Futures NZ project shared both the scenario parameters and the modelled outcomes with experts in the country's protein value chains. Additional research was done through an online survey that was accessible to a range of primary sector participants.

Among the experts and the survey participants, most considered the modelled outcomes to be indicative of their expectation of the range of impacts from alternative proteins. Those expressing more scepticism generally suggested that the modelled impacts were too conservative, and that the country should be prepared for more significant changes in economic and environmental outcomes. There was also a good level of agreement across the evaluations of the modelling outcomes that these indicated a need for focused policy and/or strategy to help the current protein value chains adjust.

The combined analysis of literature, expert insight, scenario development and modelling indicate several factors to consider in the development of policy pathways in the context of increasing supply of alternative proteins. In this report, we highlight five factors that emerged from a SWOT analysis of existing protein value chains in Aotearoa/New Zealand (see page 63–67 of the report):

1. It is necessary to consider the impact of alternative proteins in the context of other factors such as the increasing attention on the reduction of GHG emissions. The comparative benefits of alternative proteins relative to animal-proteins increases the potential impacts of the former on Aotearoa/New Zealand's primary sector.
2. There is a significant opportunity for the country to contribute in the supply of feed stock for alternative proteins, especially where ownership of IP or the use of native species provides a level of market power.
3. The extent of impact from alternative proteins can be expected to reflect the national strategies (in relation to food security, environmental regulation, etc.) of governments as much as market conditions.

Increased attention to and awareness of alternative proteins among consumers further raises the value of the country's reputation of the 'naturalness' of its agricultural and food products. The dairy sector is likely to experience the most significant impacts from alternative proteins, with the potential to provide plant-based 'milks' and to produce whey and casein proteins via precision fermentation. Efforts such as those initiated by Fonterra offer a potential strategy to support the viability of the dairy sector.

1. Background and Rationale

The Protein Futures NZ project was funded by the Our Land and Water National Science Challenge in July 2022 to investigate the impact of alternative protein sources (including those using plants, lab-cultivation, and fermentation) on the Aotearoa New Zealand primary sector. Given that most of these alternative proteins have yet to enter the market, the project first collated a snapshot of the current state of development (both domestically and internationally), which was then used to develop potential future scenarios around the development of alternative proteins. The scenarios were used in economic modelling to project the implications of increasing protein supply for global markets and the associated environmental and land use changes for the primary sector. This report summarises the findings of the project and provides some policy prescriptions for how New Zealand might position itself in the context of developing alternative protein production.

The justification of the study came from a series of position papers by industry and government organisations in New Zealand calling for more attention on alternative and plant-based proteins (Treasury 2018; Beef and Lamb NZ 2018; Plant and Food 2018). In these papers, the alternative proteins were examined as potentially competing products for the animal protein sector. The alternative products and processes fall into two broad categories: 1) replacing animal-derived proteins with available sources of plant protein (e.g., oat milk), and 2) cultivating artificial proteins that substitute for mainstream animal proteins like meat or milk. Both developments were recognised in those reports as having uncertain, but potentially significant implications for the future of food production, scientific endeavour and broader patterns of land-use in Aotearoa New Zealand. Responding to these projections, this project was funded to model the potential challenges to existing animal protein supply chains as well as the opportunities for plant-based proteins to contribute to more diverse land-use use by primary industries.

While new technologies are a centre feature of agricultural development, the replacement of animal with alternative proteins has the potential to be particularly disruptive of well-established value chains. While alternative proteins currently represent only 2% of the global meat market by weight (Morach et al. 2021), this substitution coincides with stagnated market growth for meat proteins (Changing Market Foundation 2018). New cellular technologies for producing artificial proteins present an alternative combination of untapped promise and potential for major changes to agrifood systems (Dance 2017; Mattick 2018).

Start-ups producing a range of substitutes for animal-derived proteins grew from 18 in 2017 to over 300 in 2021. The Good Food Institute (GFI), a non-government organisation with a leading role in promotion of alternative proteins, reported that there were 156 companies active in the cultivated meat industry (up from 76 in 2020) (GFI 2023a) and 136 precision-fermentation companies (GFI 2023b) by the end of 2022. A further 40 companies were reported working in the developing service sector associated with alternative proteins. The GFI (2022) also calculated that the alternative protein market received $2.9 billion in investment (down from a high of $5 billion in 2021 and similar to that in 2020). Of the 2021 figure, cultivated protein received $1.4 billion and precision-fermentation based protein $1.7 billion, with other alternative plant-based foods receiving $1.9 billion. Recent reports in the media, however, have argued that this is still a trivial contribution given the overall size of the global protein economy and that the pace of expansion has massively slowed in an era of higher interest rates (e.g. The Business Times 22/6/2023).

The extent to which the growth of alternative proteins will be transformational for the global food system is a topic for debate. International investment advisors like the Good Food Institute and Boston Consulting Group (BCG) are keen to advocate for the environmental and health

benefits compared to animal proteins. BCG (2022) completed an assessment that identifies that plant-based proteins (by replacing animal proteins) provide the highest climate mitigation return on investment at 4.4 gigatons of CO2e per $1 trillion invested. This is three times the next highest area of cement alternatives. At the same time, alternative food scholars have argued that the new technologies are more likely to increase the corporate domination of global food systems (e.g. Howard 2022). The literature reviewed for the project also suggests that alternative proteins may complement rather than replace conventional proteins.

Consequently, an expansion of cultivated and precision-fermented protein could have dramatic consequences for agricultural landscapes; but the extent of this change has been hard to appraise. Agricultural crops are currently seen as the main source of growth factors for the production of cultivated meats, including GE barley (ORF Genetics) and tobacco (BioBetter), while current precision fermentation companies use sugars from plants, such as corn to feed the yeast in bioreactors (Perfect Day). As plant-based products replace animal-based products, the need to replace animal fats with increased plant oil production could exacerbate landscape impacts. The trajectory of these impacts is, however, subject to whether intensive livestock landscapes are simply replaced by monocultures (Guthman et. al. 2022), partially negating the environmental promise of a transition to plant, cultivated and precision-fermented protein, or anchored in the transition to a more diverse landscape mosaic.

The potential for alternative proteins to both solve environmental and socio-economic challenges, and/or negatively substitute elements of existing value chains, are particularly acute in the case of Aotearoa New Zealand, where a significant amount of existing pastoral farming production is devoted to animal proteins. However, being a relatively new technological revolution, there has been little sustained and granular analysis of how the promise/peril trajectories might play out.

The early analyses, particularly by Treasury (2018), Beef and Lamb NZ (2018) and Plant and Food (2018), pointed towards the importance of these questions, recognising the significance of this emerging vector of technological innovation. Further evidence of the developing alternative protein sector in Aotearoa New Zealand was gathered in a stocktake of domestic science programmes undertaken by Thompson and Palfreyman (2021). They identified research programmes exploring both more technologically-leveraged bio-fermenting and/or in vitro cellular systems, as well as more straightforward uses of sources of plant (or insect) proteins in alternative food products occurring in multiple Crown Research Institutes(CRIs), universities and the Riddet Institute. Their assessment – ranging from oat-based milks to impossible burgers – suggested that alternative foods from plant sources could be a major site of innovation for Aotearoa New Zealand. They did not, however, identify any of the substitutionary concerns discussed in the international literature.

Conducted in the context of this stocktake, the Protein Futures NZ project was funded to undertake a more granular social and economic analysis of potential trajectories, as well as to undertake a comprehensive consideration of the place of protein production in Te Ao Māori. This is accomplished by using economic modelling to project changes in global protein demand across a range of scenarios of potential growth in alternative protein types (plant-based, cultivated and fermented, with the former two having more impact on meat proteins and the latter on milk proteins). The objective of the analysis is to fill some of the gaps, so we are placed in a better position to model the likely landscape and environmental implications of alternative proteins.

There have been a few significant attempts to address the social, economic and environmental impacts of alternative proteins in international projects. To date, this has been largely directed towards the consumer acceptability of cultivated and plant-based substitutes for animal

proteins (e.g., Verbeke et. al. 2015; Wilks and Phillips 2017; Slade 2018). There have been fewer attempts at a broader, more strategic engagement with potential social and economic impacts in farm-based industries and regions. One exception is the Protein 2.0 project funded from Norway, which hosted an international research team (including New Zealand). Protein 2.0 has undertaken a four-year engagement with the social and economic potentials and trajectories of artificial proteins (not solely plant-based substitutes). Research undertaken in the project includes consumer modelling of market acceptability, agent-based modelling of changing farm and land-user decision-making around land allocation, and economic modelling of regional and sectoral scenarios. The research methods and results outlined in this synthesis report were strongly informed by the methodology developed in Protein 2.0.

The goal of Protein Futures NZ has been to inform policy and strategic activities related to alternative protein value chains in Aotearoa New Zealand on the basis of economic and land use modelling with input from experts in the nascent sector. Of primary importance are:

- Expansion of existing documentation of the state of the sector to address the expectations regarding trends for its growth.
- Specific emphasis on placing alternative proteins within Te Ao Māori and envisioning future productive landscapes.
- Expert knowledge, collected through Delphi methods, were used to identify a set of plausible scenarios, the economic and landscapes impacts of which were analysed through economic modelling. The modelling results provided a basis for:
    - Evaluating policy and research opportunities to facilitate the development of more sustainable and resilient productive landscapes in Aotearoa New Zealand.
    - Providing guidance as to what incentives the government and the private sector could put into the alternative protein sector in order for NZ to maximise the opportunities and provide a guide for those engaged in the industry to try and achieve the maximisation of that opportunity.

2. Methodology

The assessment of expected outcomes in the context of a nascent area of economic activity is reliant on data that represents the best estimates of experts familiar with productive capacity and potential consumer demand (Bañuls & Turoff 2011; Frewer et al 2011; Landeta et al 2011; Rikkonen et al 2006). This is especially the case where such activity is subject to emergent factors of technology, science, consumer preference, producer and processor capabilities among others (Mukherjee et al 2015; Nowak et al 2011). A well-established method for addressing this challenge is the use of a Delphi framework to gather the insights of experts and to contribute to the development and assessment of scenarios for plausible future trajectories (Rowe & Wright 2011). The resulting findings are then incorporated within economic modelling to assess the implications of the scenarios for the viability of the economic activity change in land use. Additional insight can then be gained in returning to the Delphi participants to assess the scenario outcomes with regard to their perceived likelihood and desirability.

The project deployed a modified Delphi Method using the following steps:

1. **Establishing baseline questions:** The EPNZ (2021) report provided an excellent foundation having canvassed a majority of the experts and summarised current perceptions of the state of the sector in New Zealand. This sat alongside a series of literature reviews examining: media representations, industry literature, and emerging academic literature providing social and economic analysis of the emerging sector.
2. **Delphi 1:** The initial stage of the Delphi process involved 22 structured interviews of around 30-40 minutes. The interviews were designed to initiate conversations related to the anticipated transitions associated with the introduction of new protein value chains, with insights from already identified scenarios from the Proteins 2.0 project and literature (e.g., Changing Markets Foundation 2018; Morach et al 2021).
3. **Scenario development:** Following the analysis of the interviews, and completion of literature reviews, a set of four scenarios representing differing levels of development in alternative protein value chains were identified for the modelling of protein futures in Aotearoa New Zealand.
4. **Consultation with Iwi:** Using material derived from the literature reviews and interviews, an information tool was developed for use with Māori organisations to facilitate engagement with the potential implication of alternative proteins. The information tool was then piloted with iwi groups.
5. **Economic and environmental impact modelling:** Two economic models were used to evaluate the impact of the scenarios: the Lincoln Trade and Environment Model (LTEM) projected changes at the level of international trade and Land Use and Financial modelling was applied at the national level in Aotearoa/New Zealand to develop a more granular analysis of environmental and economic impacts of each scenario at a regional level. These were developed on the basis of projections for 2035 and 2050.
6. **Delphi 2:** An online survey was deploying using the results of economic modelling to engage situated experts to reflect on the plausibility of the results. The survey was open to access via the Our Land and Water website. Invitations to complete the survey were extended to all those stakeholders identified for the original selection of the Delphi 1 panel. Feedback from other stakeholders was also invited through the promotion and sharing of a link to the survey through the OLW newsletter and promotion in the Farmers Weekly. A total of 31 responses were obtained.

7. **Delphi 2:** A selected group of 14 situated experts from the prior instruments were interviewed to provide insights into potential policy implications and strategies for possible interventions to manage future impacts.

3. Literature Reviews

The analysis of the potential impacts of the emergence of alternative proteins as a significant element of global protein markets is informed by existing literature and reporting in media outlets. Three targeted reviews — one of New Zealand media representations of alternative proteins, one of publicly available reporting on research and development, and the other of international academic literature — contribute to the initial step in the project methodology. Given the rapidly developing nature of the field, it was important to gauge the current state of the literature. The reviews complemented the initial Delphi interviews, which were conducted concurrently and were mainly informed by the EPNZ (2021) stocktake of the state of the emerging proteins sector in New Zealand. The main objectives were to update knowledge of public representations and literature in a rapidly developing field, as well as to directly inform the scenario-building process.

For the project, the literature reviews focused on developing understandings of public perspectives on alternative proteins, the industry expectations of their potential and eventual impact, the state of research on and technology development for their production and the existing insights to their role in global food systems.

3.1 Media Review

A review of media sources was undertaken in November/December 2022 and examined internet sources, as well as web-based and print journalism. A total of 36 articles were collected and analysed for broad themes and emerging matters of concern.

General Findings

For the most part, the media sources addressed alternative proteins as a potential consumer product, focusing on characteristics considered to be likely selling points for products entering the New Zealand market. The tone was generally supportive but did recognise the challenges in establishing a domestic market for the products. Less attention was given to the economic potential of alternative proteins in New Zealand primary exports.

- All the sources deploy claims about the potentially healthy & nutritious contribution of alternative proteins. A number also invoked the idea that alternative proteins might contribute to sustainability goals or might contribute to less use of livestock and thus mitigate some animal welfare concerns.
- Media and online sources are not necessarily directed towards a vegan or vegetarian audience. The pitch was generally aimed at people wishing to consume less meat or dairy rather than totally avoiding them.
- A consistent and strong claim was that alternative proteins would contribute to reducing GHG emissions in farming by directing a significant amount of production from animal-based to plant-based activities.
- Cost was identified as the key barrier to overcome, as existing farming systems are still producing proteins significantly more cheaply than the alternative proteins (lab-based) and slightly more cheaply than plant substitutes for basic animal proteins. Many articles speculated on the speed at which this gap might close.
- The tone of most of the media reporting did address both the potential benefits as well as possible pitfalls of alternative proteins.

- An important theme in some media reporting was that interviewees identified that overall, there was a lack of the kind of capital investment/infrastructure and scientific capacity to support this development in NZ.

Plant Proteins

The representation of plant-based proteins in the media focused squarely on their potential to replace existing animal protein production. This included some attention on the uses of plant proteins, including those that already have established markets. The consumer focus is less predominant with plant proteins (perhaps due to familiarity), with more assessment of their potential impact on agricultural producers and processors.

- Media articles report that plant proteins are not an entirely alternative new product, noting the many plant-based protein substitutes already in the market. The most common uses identified protein supplements from legumes like peas to create protein powders or alternatives to whey-based proteins.
- Articles suggest that New Zealand has a good potential growing environment for some legumes that are commonly used as sources for plant proteins.
- The market for plant-based proteins is reported as being relatively stagnant due the current high cost relative to animal-derived proteins.
- There is an opportunity for farmers to grown the plants, but challenges to how proteins might be extracted to produce a higher-value product.

Precision Fermentation of Proteins

Fermented proteins are presented as a more alternative protein source, drawing attention to the ability to replicate animal proteins using microorganisms as opposed to the animals themselves. These products are represented as having good potential to disrupt existing protein supplies, with technologies that are closer to industrial scale production. While still represented as an environmentally friendly alternative, media reports also recognise the critiques of limited analysis of full life cycle impacts (including the need to produce the feed serum) fermentation. The media reporting also notes that because it is currently possible to produce a milk analogue through fermentation, it is more likely to compete with the dairy sector and the supply of dairy ingredients.

- The media identifies fermentation as a particularly interesting area. Protein produced through fermentation is presented as potentially the biggest threat to the New Zealand dairy industry, as bovine milk is already being successfully produced through precision fermentation.
- Compared to other alternative cultivated proteins, this is relatively simple do to on a large scale.
- There are some questions about the transparency of the carbon footprint in the industry which might be important if the products are being marketed as more environmentally friendly.
- A key threat is that currently 74% of our dairy exports are in ingredient form — which might be quite easily replaced by an alternative protein once they reach price parity or become cheaper than animal-produced proteins.
- Media articles noted that Fonterra have since invested in precision fermentation and Nestle have also made a commitment to use precision fermented dairy ingredients.

Cell-Cultured Meat

Despite attracting a significant portion of the financial investment in alternative proteins, cultured meat received more sceptical coverage in the media. This is largely due to the lack of technology for production at a marketable scale as well as the cost of the product. The cultured meat, while identical to meat proteins from animals, is also subject to criticism on the basis of not being 'natural'. In the media, the emphasis is on the laboratory provenance and the petri dish rather than the quality of the product.

- Media articles considered this to be a less significant threat to primary production in New Zealand because the cost of production is extremely high, and while it is reducing there is a long way to go to undercut animal products.
- Because of the long start-up process and costs, there might be difficulty attracting investment into this area.
- Media articles noted the overall trend is back towards natural products generally, but this doesn't seem to include lab-grown products as natural.

Overall, the analysis of media articles provided an insight to the state of discussion and public awareness with regard to alternative proteins at the end of 2022. Plant-based proteins were represented as relatively mundane, and their potential impact limited given consumer experience with and response to existing products using plant proteins. Proteins produced via fermentation and cultivation are presented as alternative, and to some extent less than natural substitutes for animal proteins. While the health and environmental benefits are promoted, the value of the alternative proteins is still uncertain. There is also some recognition of threats to New Zealand producers from precision fermentation of dairy substitutes, whereas cell-cultured meat is seen as having less potential to substitute for meat products.

These general observations do not, in themselves, provide a basis for the development of the scenarios used in the project's economic modelling. They do, however, provide significant insight to the context in which alternative proteins are understood and their economic potential is interpreted by New Zealand industry and public.

3.2 Reported Research and Development Review

Academic Literature Review

Further insight to the state of the alternative protein sector was sought through a review of academic literature on alternative proteins from 2020 (Rosin 2023). Recent reviews into the media and popular representation in New Zealand and internationally undertaken by Helliwell and Burton (2021) and Sinclair-Thompson (2022) were used to set a baseline against which the more recent literature was considered. The objective was to assess the extent to which academic publication on alternative proteins (ranging from food scientists and engineers to the assessment of food systems implications by social scientists) reinforces the promotional optimism in the financial world (see GFI 2023 and BCG 2022), or perhaps introduces a cautionary narrative.

The overarching finding of the review is that much of the literature, particularly that written by food scientist, biologists, chemists and engineers, is focused on the promissory nature of emerging proteins. That is, this literature promotes the potential for alternative proteins to 'solve' the problem of an increasing global demand for protein associated with a larger and wealthier human population, while reducing environmental (climate change and biodiversity, in particular) degradation and animal welfare issues. There are few examples in this literature of analysis of the actual progress of alternative proteins and their applications to date, nor was

there much consideration of the potential threat to land-based sectors associated with the development of alternative proteins (with exceptions like Burton 2019, 2020). Thus, the academic literature mainly includes diverse reviews and repeated claims regarding the anticipated viability of emerging proteins with only limited reference to limitations or negative consequences.

For example, the more influential work (based on the level and extent of citation), appears in the form of 'blueprints' and 'roadmaps' for development of the sector produced by government and other policy agencies. This work is largely focused on developing research strategies in diverse areas of research (from nutrition to biochemistry to food technologies among others) and has also informed a growing body of reports intended to influence government policy (Barakat et al., 2022; European Environment Agency et al., 2020; FAO, 2022; Froggatt & Wellesley, 2019; GAO, 2020; Stallmann, 2022; Te Puna Whakaaronui, 2022). There is less attention to assessments of the actual potential or relative value of the emerging proteins, a feature that appears to be an accepted fact for researchers contributing to the literature.

Alongside this policy work are a body of reports that are developed by organisations with interests in promoting the development of the alternative protein sector including consulting groups such as Boston Consulting Group (Witte et al., 2021) or non-governmental organisations such as the Good Food Institute (Cohen et al., 2022; Gyr, 2022). The promotional nature of such analyses feeds the promissory focus of the academic literature, most of which cites such projections as confirmation that the sector is growing – and frequently that such growth is inevitable. The emphasis on positive potential is also identified in reviews of the main media narratives (see, Helliwell & Burton, 2021; Sinclair-Thompson, 2022) which report a similarly strong orientation in media reporting. This did contrast slightly with the media review undertaken for this project, as well as other literature emerging locally, which showed that recent media in New Zealand had made a more concerted attempt to include some material that questioned the cost, infrastructure deficits or research capacity deficits that might negatively influence the uptake of alternative proteins in New Zealand. The review of this segment of the academic literature can directly—and in combination with the Delphi interviews--inform the scenarios developed for the economic modelling in this study. On its own, it would suggest that protein scenarios be uniformly bullish on the production potential and environmental benefits of these proteins.

Another segment of the academic literature raises the need for some caution in regard to the full-scale optimism that pervades much of the literature. This work applies a more critical perspective on protein production chains that are subject to capture by corporate interests. The analysis ranges from the examination of the financial drivers that influence investment in protein technologies (see Biltekoff & Guthman 2022, Guthman, et al. 2022) to questioning whether the concentration of production in the control of multinational food corporations contributes to a more sustainable and just food system (see Howard 2022). While a smaller body of work, it does identify a need for more cautious assessments of the sector and warrants the inclusion of less bullish predictions in the scenarios.

The main points to take from the literature review:

- The academic literature, similar to media and popular representations both domestically and internationally (see Helliwell & Burton, 2021; Lonkila & Kaljonen, 2021; Sinclair-Thompson, 2022), is predominantly positive with regard to value and potential for commercialisation of emerging proteins.
- Much of the literature identifies research objectives that address current limitations in the production process or the perceived desirability of the emerging proteins or products

produced from the proteins. The viability of the sector is either not addressed (being represented as an inevitability) or substantiated by reference to a limited number of market projections, many of which are from investment interests.

- Assessments of the capital investment processes for startups in the industry highlight the importance of promotion and positive projections to attract venture capital.
- There are a limited number of contributions that provide critical assessments of the viability for commercialisation, and these are produced by people external to the protein industry.
- The main body of critical literature focuses on the lack of transformative change that might be expected solely through the introduction of alternative proteins. The arguments used in these critiques are similar to those used by established social movements and other social actors who have influenced consumer attitudes with regard to food purchases in the past.

These findings point to the need to consider a range of scenarios, including those that incorporate the optimism of most of the literature as well as others that reflect areas of potential weak development due to the critiques and potential push-back from social movements — albeit which, at this point in time, has not happened.

The review arrives at these findings by categorising the academic literature according to three major themes:

- The imperative of sustainable diets;
- The promotion of viability of emerging proteins in production and markets; and
- The theorisation of emerging proteins as a factor in food system transformation.

Alternative Proteins and Sustainable Diets

There is nearly universal agreement in the reviewed literature that emerging proteins should be considered in the context of sustainable diets — that is, diets which would result in the mitigation of human-induced global climate change. Much of the literature is predicated on the assertion that, in replacing production of meat and dairy based protein, emerging proteins will reduce greenhouse gas emissions attributable to the global food system. Much of the analysis refers to the Lancet-EAT analysis and recommendations regarding what would comprise a sustainable diet, the central tenet of which is a significant reduction in the consumption of animal proteins with the intention to alleviate the climate, biodiversity, land use and animal welfare impact of those proteins within a nutritionally sound diet.

Literature contributing to this theme largely focuses on emerging proteins as an essential feature in realising these diets. Much of the literature on the contribution of alternative proteins to sustainable diets follows a relatively simple logic that more proteins, with less from animals, produced more cheaply, will automatically equate with a more sustainable food system. The critical points addressed under this theme focus mainly on the need to consider more complex dynamics than this simple logic would suggest, particularly the diverse contexts (social, cultural, economic, political) within which emerging proteins are likely to have unique impacts.

A broad and critical analysis of the linkages of emerging proteins to sustainable diets is undertaken by Katz-Rozene et al. (2023) with the purpose of characterising the thematic differences in the literature. They build on earlier work by (Béné et al., 2019) that had suggested that there were inherent tensions in the different narratives underlying approaches to sustainable food systems, which reflected the distinct focus on different dimensions of sustainability.

Whereas the challenges for cellular and cultured proteins are predominantly identified as addressing the upscaling of production and uncertainties of the nutritional and other characteristics, the issue for plant proteins remains the infrastructure required for processing them into forms that are palatable and more digestible. There is the imperative to develop improved consumable forms of plant proteins which requires interdisciplinary and collaborative research to address the complexities of food systems. Similar analyses have been conducted looking at other sources of protein including soybeans (Messina, 2022) and peas (Shen et al., 2022) specifically as well as insects (Liceaga, 2022), including insect cell culture (Rubio et al., 2019), fungi (Souza Filho, 2022), microbial (Areniello et al., 2023) and seafood (Steenson & Creedon, 2022). Each of these reviews look to establish the viability of a particular research or commercial area, simultaneously highlighting the significant potential of the different protein sources while identifying the limitations to larger-scale commercialisation.

As a whole, the literature contributing to this theme represents (or in limited cases challenges the representation of) emerging proteins a promissory technological development. These proteins are assumed to be an inevitable part of our food systems, providing necessary environmental, health and animal welfare and other benefits for a sustainable future. Other than the few sceptical assessments, this literature attributes accepted, if yet not fully proven, value to these proteins and the investment and research required for their development. Such arguments set the stage for arguments regarding the imperative for rapid and well-funded research that addresses the current limitations to the eventual commercialisation of emerging proteins.

In terms of developing scenarios for the Delphi process, this literature promotes a lot of upside for growth in this area, and the potential to resolve sustainability issues, but there is enough critical literature pushing back on some of the assumptions being made in most claims around sustainable future diets to warrant caution towards only developing highly positive scenarios for future growth.

Alternative Proteins and Viable Production/Markets

The imperative of achieving viable production of emerging proteins is the underlying purpose of the second theme. This theme includes the greatest number of publications, but also the greatest level of replication of arguments and topics. Most of the contributions look to elaborate the potential research contribution from a specified disciplinary area (e.g., nutrition and food science, food engineering, biochemistry, etc.), with the value of increased production and consumption of emerging proteins a taken for granted fact. Included in this theme are the limited number of contributions that identify existing limitations as technological barriers, as opposed to challenges to be overcome through further research.

The most common format of the work in this theme considers the potential contribution of specific disciplines or areas of research. For example, Mateti et al. (2022) review the current state of the emerging proteins sector from the perspective of materials science and engineering, focusing specifically on the meat analogues as material replacements for meat. Similar claims for increased research and investment are made to advance nutritional quality: the ‘structuring technologies’ (Lee et al., 2022), consumer acceptance (Boukid & Gagaoua, 2022; Kołodziejczak et al., 2022; Lima et al., 2022; Thavamani et al., 2020), regulatory oversight (Chodkowska et al., 2022) and upscaling (Broucke et al., 2023) of emerging proteins.

A smaller contribution to the academic literature addresses some features of emerging proteins that have the potential to undermine their contribution to food system transitions. A significant concern remains the cost of producing these proteins, with some modelling of the upscaling of production suggesting that technological constraints will limit economic viability (Humbird 2020,

2021). Similar concerns have been raised about food safety, contamination and allergenic properties (e.g. Kopko, et al. 2022). It is also noteworthy in this context that there is minimal analysis of the economics of the emerging proteins[1]. Treich (2021) specifically seeks to address this absence, but notes that there is a lack of available economic data on commercial production of cultured meat, making for a largely speculative analysis.

The most well-furnished area of research into the potential for alternative proteins to upscale production concerns emerging consumer responses and potential market success. Most of this research involves standard attitudinal surveys or choice experiments set to gauge the potential purchase of the products (albeit usually in the absence of the product). The general findings in this literature identify significant consumer interest in trying alternative proteins for environmental, animal welfare and, to a lesser extent, nutritional reasons (Cardello et al., 2022; Chezan et al., 2022; de Koning et al., 2020; Dean et al., 2022; Demartini et al., 2022; Hamlin et al., 2022; Nguyen et al., 2022; Pasqualone, 2022; Rombach et al., 2022). Meta-analyses of the consumer preference studies are the basis for recommendations to enhance consumer acceptance of the proteins (Siddiqui et al., 2022). The promotional efforts of the industry are also subject to critical assessment, with the claims to Better Meat being 'hocus-pocus' (Ryynänen & Toivanen, 2022), supported by a 'fluttering veil of trust' (Kjærnes et al., 2022) and developing 'conscious, complacent and fearful' consumers (Biltekoff & Guthman, 2022).

Consequently, while much of this literature does explore specific products or specific economic or market segments, for the purposes of developing future scenarios for New Zealand within a Delphi method, the literature reviewed in this section largely provides context for scenario development but offers very little in terms of specific growth expectations.

Alternative Proteins and Just, Equitable and Sustainable Food Systems

The final theme emerged from a body of literature that investigates the extent to which emerging proteins might be the driver for transformation to a more sustainable or just food system. The contributions to this theme are predominantly the work of authors active in the assessment and critique of food systems from social science perspectives. As a result, these analyses question the kinds of underlying value claims for the development of emerging proteins that are generally 'taken-for-granted' in the food science-based literature addressed in the previous two sections. Due to the nascent character of emerging proteins, the analysis is largely theoretical with insight influenced by understandings and assessments of existing social, political and economic relationships in the current food system.

For example, Helliwell and Burton (2021) document the 'visions' of cellular agriculture as these are represented in news and industry media. They note a similarly overwhelming emphasis on positive representations of cellular agriculture, which is promoted as a solution to environmental, animal welfare and food security issues in the existing agricultural system. They also identify silences in terms of the potential problems associated with the alternative technologies of production including the creation of new forms of monoculture (in laboratories), new environmental problems associated with the energy and feed stocks required and questions regarding the change in demand (and accessibility) of protein that is sourced from laboratories rather than farms.

In another widely circulated recent critique, Guthman, et al. (2022) reinforce the problem of silences, arguing that promotion of emerging proteins more generally is too focused on a

[1] This does not include the sector overviews developed by investment groups such as the Good Food Institute (Cohen et al., 2022; Gyr, 2022) and Boston Consulting Group (Witte et al., 2021).

perceived scarcity of protein rather than the environmental and social implications of a shift to alternative protein sources.

In terms of filling out the spaces and silences that exist around the pro-protein literature's characterisation of the wider agri-food system, various critique fill in the gaps. Howard (2022) points towards negative corporate behaviour in agrifood systems, while Chiles et al. (2021) see the negative effects of concentration of financial capital in food systems being simply exacerbated. Fairbairn et al. (2022) also argues that the new startups are not disruptive of existing financial structures. Other critiques focus on the use of animal meat as the acceptable benchmark for comparison (e.g. Lonkila and Kaljonen 2021; Stephens et al. 2018; Evans and Johnson 2021). In sum, the logics behind protein as a 'building block' for constructing nutritional foods (Guthman & Biltekoff, 2022; Sexton, 2020), make it an extremely attractive target for investment seeking greater control of the consistency and quality of production. On the other, the lack of transformative capability in current development trends exposes the emerging proteins to ready critique and potential consumer protest action.

This segment of the academic literature suggests that, while most literature is positive, critical social scientific analysis has identified justice and equity issues that might become the basis for future social movement critique – which, again suggest the importance of using caution in developing scenarios that focus only on high levels of growth.

Literature on New Zealand

Perhaps the most relevant academic literature for the project was specifically directed towards New Zealand. Interestingly, and reflecting the brief media review undertaken in this project and reported earlier, the New Zealand literature is not so universally accepting of promissory claims about the future of alternative proteins. It is noteworthy that the majority of this literature investigates consumer preferences for emerging proteins. The small number of publications considering the production and development of these proteins appears to focus on minimising the 'threat' they would exert on existing, animal-based protein production in the country.

The rapidly expanding literature on emerging proteins internationally is somewhat at odds with the relative lack of attention to their development in published academic research conducted in the Aotearoa/New Zealand context. There is, for example, no comparable analysis to those of Germany (Moritz et al., 2022), the USA (Newton & Blaustein-Rejto, 2021) or Brazil (Morais-da-Silva et al., 2022a, 2022b) that assess the implications of an expanding alternative protein sector for animal protein value chains or the landscapes of the country. This is the case despite the recognised likelihood that emerging proteins will impact the perception of the animal proteins that form a significant portion of the economy in reports to government policymakers (see Eason & Pena, 2018; Te Puna Whakaaronui, 2022; Thompson & Palfreyman, 2021). Indicative of the country's current concerns, the literature that is available provides either a defence of conventional animal protein production or evaluates the acceptability of alternative proteins amongst domestic consumers.

Emerging proteins are not addressed specifically in relation to their production potential in the academic literature in Aotearoa/New Zealand. Caradus et al. (2022) do, however, dedicate a section of their review of pastoral production to the impact of alternative proteins. The main objective of the article is to celebrate the past success and future potential of the overall production of animal proteins in the country. As a result, the section on emerging proteins first highlights early-stage development of a protein extraction process from ryegrass as well as the potential to produce high quality inputs as feedstocks for cultivation and fermentation of proteins. This is followed with a sceptical review of the challenges that emerging proteins face including the claims to nutritional and environmental benefits and the likelihood of consumer

acceptance of alternative products. Based on this assessment, the authors discount the likely impact of emerging proteins on demand for protein from the domestic pastoral systems, suggesting that they are part of a broader economic and social context that pushes the sector to increase productivity while reducing environmental impact and meeting animal welfare goals.

Similar treatment of emerging proteins as being more of an opportunity than a threat is provide in published work on alternative sources of protein from existing crops. Kaur and colleagues (2021, 2022) report on research conducted at the Riddet Institute in Palmerston North. Both articles focus on the challenges of improving the digestibility of plant proteins with the goal of bringing them on par with animal protein digestibility. The first article refers specifically to the process of extracting a protein-rich powder from rye grass and is presented as offering greater flexibility in use of pasture for farmers. Teixiera, et al. (2022) reports on initial research in the development of lucerne as a source of plant protein. The rationale is, again, to provide an alternative source of income for farmers, taking advantage of growing international demand for plant-based proteins and not a response to the threat of emerging proteins to existing production systems.

The final area Aotearoa/New Zealand focused literature addresses consumer preferences with regard to emerging proteins. At a more general level, Coetzee (2022) examines the motivations for adoption of a flexitarian diet by consumers in the country. Her analysis of self-identifying flexitarians identified distinct drivers and considerations for preferences in meat and plant-based proteins. This suggests that consumers do not expect the plant-based proteins to completely mimic meat proteins. Cardello et al. (2022) report on consumer segmentation identified in a taste test of plant-based and dairy milks. Their findings included the recognition of a greater than anticipated diversification in preference, including 'intermediate' groupings between the extremes of the *full-fat dairy likers and plant-based likers*.

In an investigation of consumer response to cultured meat, Hamlin et al. (2022) noted that consumers did not simply differentiate between conventional and emerging proteins in their preferences but would also react to the particular source of protein with insects eliciting the greatest disfavour. Similar variation in consumer response to cultured meat was also identified by Giezenaar et al. (2023), who identified distinct factors in the attitudes of Millennial as compared to Generation X aged consumers. In an analysis of consumer perceptions of in-vitro meat, Mallavelli et al. (2021) identify a range of factors, including sustainability, health and safety and current behaviour, that influence current perceptions of the emerging proteins.

While not specifically addressing the implications of emerging proteins on the country's existing production systems, the results of these studies contribute to the general absence of clear statements about the impact of these proteins. The diverse responses identified suggest that consumer demand for emerging proteins will not result in the total rejection of animal-based proteins, an outcome that further dampens the perceived threat to existing production. The observation of a limited sense of urgency in the Aotearoa/New Zealand academic literature with regard to the impact of emerging proteins is similar to that identified by Sinclair-Thompson's (2022) analysis of future-oriented narratives of proteins in the domestic media. In his reporting, Sinclair-Thompson notes that there is a high level of interest in emerging proteins, but the message to the sector varies significantly from needing to prepare for a disruptive influence to navigating a changing protein market in which claims to quality and sustainability are increasingly important. In addition, he notes that the implications for future landscapes and community wellbeing (two of the silences identified by Helliwell and Burton, 2021) are not fully addressed.

As a whole, the literature focused on the context of Aotearoa/New Zealand provides a strong contrast to the broader literature lacking the extreme promissory claims and, more notably, the

references to the imperative of a food system transition based in emerging proteins. This suggests that the protein sector in the country may be significantly unprepared for a world in which emerging proteins were to largely replace animal proteins in the global food system. That said, they may be better positioned to manage their participation in a future defined by more moderate uptake of emerging proteins. It is fully apparent, however, that – at least in the relatively near-term future — emerging proteins will not be the driver of food system transitions in the country, given that neither the carrot of domestic demand for alternative proteins nor the stick of disapproval or sanction in global markets have eventuated. These two parameters were influential in shaping the scenarios in the Delphi process in this project.

4. Initial Interviews (Delphi 1)

An initial round of interviews was conducted with stakeholders during December 2022 - January 2023. The timing of the interviews coincided with the media and academic literature reviews and was designed to provide some on-the-ground information that would help inform the development of scenarios for the subsequent Delphi process. A fuller version of this section can be found in Sinclair-Thompson (2023).

Researchers from the AgriBusiness Group conducted 22 interviews with key informants from industry and research in the protein sector representing a range of perspectives (from pessimistic to very optimistic) on the potential of alternative proteins. The interviewees were selected from a list of 177 people known to be working in the emerging protein space, including attendees at the Emerging Proteins New Zealand conference, in addition to representatives of various agrifood industry, government, and research organisations. Thirteen were removed from the list to avoid doubling up on interviews related to the concurrent MPI protein roadmap initiative. Those remaining on the list were sent a brief survey to gauge their interest in contributing to the research and to establish their role, level of understanding, and particular interests. Out of those who had responded and were willing and available to participate in interviews, the final 22 were selected with the intention of providing representation from each of the key drivers identified below, with the exception of Māori Development Opportunities, which will be addressed in separate reporting.

Selection of Interviewees: Drivers of Sector Development

1. Regulatory/Governance/Policy
2. Cost of Production
3. Technological Development
4. Environmental Impacts
5. Protein or Alt-Protein Market
6. Geographical Distribution
7. Supply of Clean Energy
8. Consumer Response
9. NZ Business Dynamics and Response
10. Global Scale Challenges
11. Māori Development Opportunities

As the interviewees were being asked about future scenarios, many of their responses did take on the promissory style being discussed in the international academic literature review (above). But from the outset, many in this group saw the future as being highly uncertain, and could only be understood as the outcome of interactions between multiple drivers. Unsurprisingly, a 'food futurist' offered perhaps the most comprehensive example of an attempt to bring together multiple complex drivers of what the future might hold:

> *"I think it's okay at the country level for us to play at the premium, at the middle market, and the commodity market, and that's already what we do. I think the same will emerge for these emerging proteins as there will be some in the premium market, there'll be some in the middle and there'll be some for I call it food for people with no choice, so: prisons, hospitals, old people's homes.*

> *All of those markets will be covered and so the economics are different in those three markets. What the economics are in the mass market, it will make a real difference to what the inputs are. And we may find that marginal land that can be put into crops might be a great place for those providers. Whereas at a high end, it might need to be regen or organic and so I think (...) it will be economic in multiple ways.*
>
> *You know, farms already are diversified businesses and I think we should expect that this will be a diversified industry and there will be different drivers for different people, so some will also replace existing, either grass or crop or forests or meat or dairy at an environmental level. We've already seen it with a bunch of the vertical farms in the US that their ability to do controlled indoor agriculture that is organic, without pesticides, and an absolute minimum of fossil fuel based fertiliser means that they can compete in a low-carbon economy, particularly when they use solar power and they walk their product to market. There's a whole lot of efficiencies that come in for that vegetable and fruit production that makes it very climate friendly. I think we will see products like that in the emerging proteins area where they will compete on, you know, what's the emissions per kilo of protein or available protein."*

As demonstrated in the quote, this respondent was seeking to balance multiple, complexly interacting drivers: from the projection of the 'country level', demarcating markets along the particular food-choice agency of their consumers given their social circumstances, and only then inviting us to consider the metrics that will determine the efficacy of the various technologies to fit into this world of multiple niches. This is a complex promissory narrative and starkly contrasts with any attempts to create a narrative in which we make linear progress towards desired future states.

4.1 Plant-based

Inevitably, as the only technology currently in market in Aotearoa New Zealand, plant-based proteins attracted the most commentary. There was a general consensus amongst interviewees, with a few notable exceptions, about the potential to grow plant-based proteins, largely framed as a form of diversification; however, that could be approached in a number of ways. The following quote by an agricultural scientist displays a particular concern for the risks built into the current production system:

> *"Is there space and opportunities for New Zealand to grow [plant-protein]? The answer is yes, as well and particularly I think if the country wanted to diversify itself (...)*
>
> *I see it as a mitigation strategy to reduce risk for the country as well; New Zealand cannot rely on meat and dairy forever. There is a huge risk around that even though it continues to sell well every year, (...) as a country, for its future, I think it's the risk mitigation strategy, for the country, it needs to go [to a] much more diverse agricultural production system."*

The emphasis on risk invokes the caveat of the unknown that comes with any future imagining. In this instance, the interviewee identified diversification as a mitigation strategy by facilitating the possibility of alternatives in the event any single system fails.

Whereas the above quote emphasised change from a country-scale perspective so as to emphasise the role of regulatory bodies in driving a coherent national economy, the following from a plant-based start-up put the farmer front and centre:

> *"For us it's about achieving scale, but doing that in a way that allows farmers to come on the journey with us, or we go on it together, so the way we envisage the farming system working now and it will as we work more closely with farmers, change over time, but adopting a fraction of their land into the (...) system that's dedicated to the plant protein supply for human consumption and then the co-product feed coming off that can go off into the animal system.*
>
> *So it's not like this replacement type system, it's complimentary, and then as the market validation happens over time, or we can see that there's other benefits for whatever that cropping system or the loop (...) system provides, it can grow from there. (...) To that point one other thing is also seeing a big concern for processors going forward, seeing as though we've reached peak milk and it looks to be going on a downward trajectory, so designing our own system in the way in which we could integrate within the dairy system, albeit we do have some differences, but how do we utilise that stainless steel, that's probably going to have (...) greater capacity challenges."*

Firmly rooted in a farm-systems perspective, the quote demonstrates an approach to the issue of scaling up that attempts to fill in the gaps of an overextended pastoral agriculture via diversification, both on farm and in processing.

As far as drivers were concerned, the role of a government push as opposed to an innovation pull was one important tension for some interviewees to negotiate, and upon which responses can be contrasted. To round out the two previous quotations, this from a financial advisor recognised the role of government regulation on farmer decision making:

> *"I think it has the potential for greater diversification and not just at an aggregate national level but within farming systems.*
>
> *I think the basic economics around the costs we're imposing on livestock production to externalise some of their environmental impacts are discouraging further investment in that space and tipping it more to non-livestock production systems that don't have those costs, so I think over time, you know, farmers will look at is there a proportion of my property that I can put into a crop for alternative proteins.*
>
> *But again, I think it's still a relatively slow burn, so you know in the next couple of years maybe won't see massive uptake but then if you do look ten years out… yeah more opportunities in that space.*
>
> *I'm not sure at this stage that it's going to be a game changer for land-use or anything like that."*

4.2 Precision Fermentation

In contrast to the plant-based proteins, precision fermentation served as a truly alternative terrain for many respondents. Though most had heard of developments overseas and many were well up to speed with market shifts, in the absence of direct industry involvement, interviewees had to make use of hypotheticals and analogies to construct their future narratives.

The following quote from a former food-trends analyst attempted to integrate precision-fermentation into the Aotearoa New Zealand agrifood scape:

> *"By 2050, I think it's going to be a part of our commodity make-up. So, you know, at the end of the day you don't care, right? You're buying the milk to put into a chocolate bar (...) It's the same thing. Same cells same structures, all those things. It's the scalability that's stopping it from growing globally, regardless of New Zealand.*
>
> *But I think in New Zealand we'll still farm; but what will support us being able to farm will be the fact that we can take the volume. You know you might not have a milk curve. You might not do winter milking anymore (...) What do you do? You crank up your vats in winter and you do your cheeses and all your other things in summer when the production's coming in."*

The quote demonstrates an attempt to turn precision fermentation into something legible for current dairy operations. The implication of the world commodity market turning to fermentation is that pastoral-based dairying fills a premium market, in which instance fermentation is predicted to supplement pasture as a means to facilitate de-stocking and a less intensive dairying. Several absences remain, however; for example, how the dairy industry would survive off of an exclusively premium market, or how precision fermented and pasture-based dairy would sit alongside each other.

Carrying over from the plant-based commentary, the projected decline in stocking rates was expected to provide an opening to diversify processing, possibly to enable either precision-fermentation or cell-cultured proteins, as illustrated in the following quote from a financial advisor:

> *"In terms of that fermentation space, I think there is an opportunity here because (...), if we're anticipating based off climate change commission data that we're going to have a 12% decline in sheep and beef stock units in New Zealand by 2030, we're going to have to run into issues around processing capacity. We've had an overprocessing supply the last few years, but now with labour shortages that's somewhat improved, so I think meat companies are going to have to start looking particularly in the sort of Gisborne area and through Otago, we're going to see ongoing land-use pressure for change to trees. What do we do with all our processing facilities, what do we turn those into?*
>
> *And the dairy industry may face some of these questions, but not to the same extent as the sheep and beef industry. What do you do with all the infrastructure you've got there: those plants, the staff? And [there], could there be an opportunity for investment or changing your infrastructure to be able to ferment or harvest, [to] provide a component of that cellular production that we export? So I think there could be some opportunities in there, and I think it's going to be up to the science community to help identify what those products could be and then working out whether there is actually sufficient financial incentives there for it to stack up really."*

As with the start-up interviewee, this advisor seeks to mobilise processing capacity so as to prompt diversification, recognising, however, that research will need to be done into the ability for such systems to transition, and the financial impacts of doing so.

4.3 Cell Cultured

Of the three emerging protein domains discussed, cell cultured was the furthest from all the interviewees' concerns, both because of the distance to the industry and the fact the technology has yet to be proven as commercially viable. That being said, interviewees where cognisant of the potential as a hypothetical entity, and a few attempted imaginative, though heavily caveated pathways. The following quote came from a former food-trends analyst:

> *"So if you look at it from a cellular base (...) you could run a farm with three cows, or three bulls or whatever because the cells in which we use them you just need to keep the progeny going. Then obviously that will have a huge environmental impact because I can still eat 7 steaks a week and you know each farmer only has to keep 2–3 cattle, because they're actually like a stock for quality cell-stock, you know, they're not a big farm stock thing."*

While the need for pasture-based meat to supply cell-cultured protein remains to be seen, should the technology take off using immortalised cell lines, the quote does demonstrate an increased emphasis on progeny as a potential driver for the future of the meat industry.

In a more hesitant tone, a plant-based protein start-up advisor sketched out their concerns, though in doing so considered the possible utility of the technology as well:

> *"The other reason why I'm sort of a little bit eerie around the whole cultivated meats area is it doesn't feel like it's a space where NZ itself has any comparative advantage. We're a long way away from markets. I mean, maybe it has for feeding our own people, and that's an important consideration, don't get me wrong; but it's certainly not the scale that our industry is, which exports most of its produce. So, thinking about because we're sort of an export growth, business growth, economic development space. Considerations are where is the consumer for this; is it suitably big enough for the market to make the process worthwhile."*

While acknowledging the technology is still far from being realised, the interviewee demonstrates in the quote that their own inability to conceive of Aotearoa New Zealand successfully implementing a cell-cultured industry impedes them from imagining a positive vision for the technology. That said, the prospects of a local-cell-cultured industry, provides an alternative discussion point. Without elaboration, the point raises questions as to what would have to happen to Aotearoa New Zealand pasture to prompt such a development.

There is a difference of tonality in much of this interview material when compared to a lot of the international literature on future scenarios for cultivated proteins. While the international literature review did prompt differences of national and geographical context (eg. the difference between speculation in the US compared to China), the situated experts interviewed in this project had a keen sense of what might and might not work in New Zealand. They were sensitised to infrastructure capacity and markets for new products, they saw the challenges created around a large a successful primary production sector, and many of them recognised science constraints and opportunities.

All these responses confirmed some assumptions — along with the lit reviews and media analysis — about what kind of scenarios might be useful to test in Delphi Two instruments. A principle insight is that responses to emerging technologies of protein production will elicit a complex set of actions and interactions. The collective interpretation of this material does not, however, result in the options for New Zealand being diverse and all-over-the-shop. Rather, it suggests the need to consider a range of scenarios to represent different potential pathways of development and response, all of which are based in current understandings of the animal

protein sector and it capacity to respond to likely pathways and thus require deeper consideration.

5. Scenario development

As stated in the methodology, the economic modelling of the environmental and land use implications for Aotearoa/New Zealand of emerging alternative protein production requires the development of plausible scenarios for the development of that sector. In a traditional Delphi approach, the scenarios would be constructed through iterative engagement with established experts, who would help to set the parameters of expected change and subsequently review the pathways suggested by the research team for accuracy and credibility. Given the uncertainty and complexity in the early stages of development for alternative proteins, the Protein Futures NZ project adopted a modified Delphi in which the scenarios reflect the low, medium and high projections for the market as established in the international literature. This approach is justified by the notable promissory nature of current academic and media reports, as well as the often speculative nature of the first Delphi interviews. Together, these give a strong indication of the commitment to expanding alternative protein production, but also the lack of clear agreement regarding the nature of this growth. For the purposes of this study, participants have been asked to examine and provide feedback on the modelled impacts (and not the scenarios themselves) to help inform recommendations for policy.

The scenario development process took place in January–April 2023, with the project team meeting to evaluate:

1. The literature and media reviews and;
2. The first round of interviews. The team then considered any emerging information on the following kinds of dynamics (that was not an explicit focus in the international literature that had been reviewed) which would influence the relative credibility of the scenarios:
    - What were current expectations for improvements in taste and texture of alternative protein products?
    - Can cost of production be reduced to an economically viable level? When might price parity between conventional and the various forms of alternative protein products be achieved? Over what timeframe was it likely to happen?
    - What is the role of the current state of regulations in New Zealand – lack of regulations or supportive regulations for alternative proteins?
    - What are the trends in consumer acceptance of products?
    - What is the current state of environmental/landscape considerations for traditional animal-based products and status of climate regulations?
    - What are current commercialisation trends, e.g. what approach have mainstream companies taken towards alternative proteins?
    - Have there been recent developments with regard to technical barriers / product development / innovation / scientific development?
    - Is there increasing capacity to scale up facilities?

The project team adopted four basic scenarios of change in alternative protein production in reference to a 2035 time horizon. The scenarios were structured around the growth potential of the three main categories of alternative proteins: plant, precision fermentation and cell cultivation. The scenarios ranged from a conservative, similar to existing growth, and developed to the most optimistic projections available in published literature. These were expected to result in significantly contrasting results from the economic modelling, and thus provide

discussion points for Delphi participants and insight to the need for policy initiatives from industry and/or government.

Table 4: Alternative Protein Scenarios 2035 Comparison

	Plant proteins	Precision fermentation	Cellular
Scenario 1 Baseline/conservative	✱	✱	▼
Scenario 2 Precision fermentation for dairy ingredients becomes competitive	✱	▲	▼
Scenario 3 Plant-based products take off	▲	✱	✱
Scenario 4 Emerging proteins take off	▲	▲	▲

Key

▲ Rapid commercial development — high growth rate

✱ Some commercial development — low rate of projected growth

▼ Commercial development stops or stalls

Each of the scenarios is best understood as the product of a set of presumptions about supply, demand and regulation trends. The following summary narratives outline the factors that differentiate the development of the alternative proteins in each scenario. The different types of alternative protein are significant to the economic modelling to the extent that they are more likely to compete with meat or milk proteins. Note that cell cultivation is the only protein in the scenarios that may fail to reach commercially viable development, whereas plant and precision fermentation have already (to varying extents) achieved that milestone.

- **Scenario 1 (Baseline scenario):** Reflects the current situation of an increased demand for alternative protein. Assumes that the production of new alternative proteins contributes towards meeting increased demand but only marginally impacts on traditional protein supply chains. Issues like technical barriers, limitations to scaling production and lack of consumer uptake cause a slow growth in alternative proteins.
- **Scenario 2:** Precision fermentation takes off as the result of technological and regulatory improvements and impacts on traditional dairy products. Demand for plant proteins continues at current growth but technical issues stall the development of cellular products. Sustainability, in combination with improved taste/texture and achieving of price parity, is a key factor driving consumer acceptance[2].
- **Scenario 3:** Plant-based products take off as an environmentally friendly alternative to animal proteins, whilst the barriers facing precision fermentation and cellular products are eased, but not completely eliminated. Precision fermentation is not able to replace traditional dairy products to the same degree as in Scenario 2. Sustainability is a key factor driving consumer acceptance in combination with improved taste/texture.

[2] This scenario focuses on the demand and consumption of fermented dairy products, not the intellectual property that New Zealand could sell regarding precision fermentation. It acknowledges that New Zealand could play a role in IP provision, but this will not be significant in this scenario.

- **Scenario 4:** All alternative proteins take off. All current barriers to the market success of the alternatives have been removed or are in the process of being overcome. Sustainability is a significant factor, price parity is achieved for all alternative proteins, taste and texture improve and alternative proteins are viewed as solving a number of global environmental and health concerns.

Table 5: Scenario summaries

Scenario 1	Scenario 2	Scenario 3	Scenario 4
• Reflects the current situation of increased demand in alternative proteins. • New emerging proteins contribute towards increased demand without significantly affecting traditional protein supply chains.	• Increase in demand for emerging proteins — Plant Proteins +10% and Precision Fermentation +22%. • Demand for emerging protein continues however technical issues stall the development of lab based (cultivated) protein products. • Sustainability is a key factor driving consumer acceptance and demand.	• Increase in demand for emerging proteins — Plant Protein +22%, Precision Fermentation +10% and Lab-based (Cultivated) +10%. • Plant-based protein products take off. • Sustainability is a key driver of consumer acceptance and demand.	• Increase in demand for emerging proteins — Plant Proteins +22%, Precision Fermentation +22% and Lab-based (Cultivated) +22%. • All current barriers to the success of alternative markets have been removed or are in the process of being overcome. • Scale of production has increased whilst regulation and market access barriers/tariffs for food are based on GHG emissions and other environmental outcomes.

With the general scenarios established, the next step was to quantify the changes in protein production. This involved identifying available projections for the sector and looking to distinguish plausible projections based in informed analysis. In addition to the work by the Good Food Institute and Boston Consulting Group, further possible sources were identified with internet searches using the following key words: “alternative proteins” “demand” “2035”; “demand for alternative proteins 2035”; “precision fermentation demand”; “plant-based demand”; and “cellular products demand”. These search criteria identified 16 potential sources for projections. Seven of these were assessed as either significantly outside the consensus of the remaining sources, based on unsupported assumptions or focused too finely on a specific product (as opposed to plant-based, precision fermentation, or cell cultivation as categories) and were not included in the development of scenarios. The pathways identified in the Morach, et al. (2021) sector evaluation by Boston Consulting Group were used as the framework for the scenarios, as the report included a comprehensive set of low, medium and high projections for each of the protein types. The remaining sources were used to confirm or adjust the BCG projections and to provide additional context for the rationale narrative.

The search for future production data provided a set of data that could be applied to the scenarios. This data ranged from projected production in weight (millions of metric tonnes, MMT, of alternative protein in the global market), the percent share of alternative protein in the global protein market and the Compound Annual Growth Rate (CAGR) through 2035. The research also looked for regional data (Americas, Asia, Europe, Pacific, etc.) to inform the

modelling using the LTEM, although such detail was limited to the BCG analysis (Morach et al 2021). The data was assessed in the context of the key assumptions underlying each projection, recognising that the reporting organisations would promote the potential of the sector and researchers in specific protein types would look to encourage additional funding in a competitive landscape.

Once the more reliable and robust data had been identified, the remaining projections were considered in relation to the four scenarios, looking to identify low, medium and high projections for cell cultivation and conservative and high projections for both plant-based and precision fermentation. Where possible, similar data (that is, quantity vs earning vs share of market) was used to facilitate comparison. To better understand the most comprehensive set of projections from the Boston Consulting Group (Morach et al. 2021), a member of the project team met with a representative of the firm to get insight to underlying assumptions that were not available in the report. This helped to verify the reliance on much of the data from that report in the scenario development.

The resulting quantities for each protein type across the four scenarios were moderated and approved by the Project Leader (Jon Manhire) and Science Leader (Christopher Rosin), addressing credibility both in terms of the scope of the projections and their relationship to the scenarios. The resulting scenario-based projections were then peer-reviewed by Dr Rob Burton, who commented on the projections based on his in-depth understanding of alternative proteins from the perspective of the European market. In each case, the projections for each of the three protein types represents an actual projected figure, although some are assigned to the respective low, medium and high development levels based on comparison with figures reported across the data collected (and not necessarily in the terms used by the group or individual providing the projection).

5.1 Scenario criteria: background and alternative protein status

An initial basis for distinguishing the scenarios involved contrasting assumptions regarding the future background for the global protein value chains and markets. This included a general background that varies from a more conservative projection that maintains current growth and market position of alternative proteins, to moderate increases in precision fermented and plant-based proteins in Scenarios 2 and 3, respectively, to a more optimistic projection of substantial growth for all three forms of alternative protein. The details specific to each of the protein types also contributed to the differentiation of the scenarios. These included economic factors (the potential to achieve price parity with traditional, animal-based proteins), technological achievements and consumer acceptance of the alternatives.

Table 6: Background and assumptions on scenarios

Scenario 1	Scenario 2	Scenario 3	Scenario 4
Background			
• The production and market for emerging proteins develops at the current rate (global situation). • The general perception is that alternative proteins (and associated technologies) on their own will not achieve a transformation towards a more just and equitable and sustainable food system.	• There is substantial growth in the production and market demand for precision fermented dairy ingredients and products driven by the perceived economic, social and environmental advantages of these products. • Price parity is achieved by 2025. • Fermented ingredients replacing milk are perceived as safe and sustainable.	• There is substantial growth in demand and production for plant protein products. This includes plant-based meat and milk. • Other emerging proteins support the development of enhanced plant-based products by producing fats and flavours, further enhancing the market position of plant-based products compared to other proteins.	• There is a substantial growth in demand for and commercial production of all emerging proteins.
Status of Plant Proteins			
• Continued current technological development and improvement of alternative meat and milk analogues. Increasingly competitive with traditional meat/milk products, however, this does not significantly disrupt the market for these products, with the analogues servicing the growing global demand for protein. • Price parity is achieved by 2023.	• Some growth in demand for plant protein products resulting from increased consumer sensitivity regarding animal welfare, environmental issues as well as improvements in the acceptability / quality / value of plant protein products.	• Substantial growth in demand for plant protein products associated with consumer sensitivity regarding animal welfare, environmental issues and improvements in quality. • All major food processors offer plant-based products. • Price parity is achieved by 2023, resulting in soaring interest and steeply increasing adoption.	• Substantial growth in demand for plant protein products associated with consumer sensitivity in regard to animal welfare, environmental issues and improvements in quality.

Scenario 1	Scenario 2	Scenario 3	Scenario 4
Status of Precision Fermentation			
• The scaling up of bio-fermentation capabilities restrained by the high capital requirements. • Slow development of strains for precision fermentation. • Feedstock for precision fermentation remains costly with few alternatives available. • Some development for specialist products but no significant pro-duction and remaining more costly than animal-proteins.	• Cost parity for precision fermentation milk in 2025 (and other addressable proteins) results in a rapid growth in processing capability and supply of milk proteins. • Regulations relaxed to support widespread use of precision fermented ingredients.	• Scaling up of bio-fermentation capabilities is restrained by the high capital requirements. • Some development for specialist products including for ingredients for hybrid/plant-based products.	• Cost parity for precision fermentation milk in 2025 (and other addressable proteins) results in a rapid growth in processing capability and supply of milk proteins.
Status of Cellular Products			
• The development of cellular proteins stalls due to technical, regulatory barriers, consumer resistance, high capital costs and minimal investment in scaling up facilities for cellular products.	• Limited development reflecting technical and regulatory barriers, consumer resistance and high capital costs.	• Limited development reflecting technical and regulatory barriers, consumer resistance and high capital costs. • Few major food processors develop production lines. • Key ingredients remain in limited supply. • Minimal perceived benefit for the environment.	• Cost parity for cellular meat in 2030 results in a rapid growth in processing capability and supply of substitute for ground beef resulting in a decline in demand and price for farmed sources.

5.2 Scenario criteria: trends as drivers of protein performance

The projected changes in alternative proteins was supported by varying sets of expectations regarding trends in markets (including consumer expectations and preferences), regulatory contexts and environmental conditions and the public perceptions of these conditions.

The market trends parallel the descriptions in the background and status criteria, with some justification based in market behaviour. These trends were also used specifically to inform the global trade modelling (outlined in Section 6.1). The regulatory trends consider the potential easing of constraints on approval of alternative proteins as safe foods, as well as any restrictions or disincentives to continued trade in animal-proteins. The environmental trends look more specifically at likely changes in how factors such as climate change, animal welfare and freshwater quality can influence perceptions of alternative and animal-based proteins as well as provide the justification for the regulatory trends.

The underlying assumption is that there will be continued efforts to mitigate climate change by reducing GHG emissions, and that alternative proteins (although noting critiques of the protein efficiency of plant-based milk substitutes) currently exhibit potential for lower emissions, through lower methane emissions, reduced land conversion and, in some cases, lower use of synthetic fertilisers. Several of the scenarios allow, however, for increased efficiency in animal-proteins.

Table 7: Market, regulatory and environmental trends used within scenarios

Scenario 1	Scenario 2	Scenario 3	Scenario 4
Market/Consumer Trends			
• Continuation of current trends for international consumer demand for meat proteins. • Limited increase in interest or demand for sustainable diets coupled with the perception that alternative proteins do not enhance sustainability. • Low consumer acceptance of alternative proteins due to such factors as indifference towards taste and texture, social norms and food neophobia, etc.	• Price parity facilitates widespread adoption of precision fermented milk (PFM) proteins for use as a food ingredient. Consumer interest in sustainable diets increases demand for PFM as a lower GHG product. • Consumer interest in sustainable diets increases demand for PFM as a lower GHG product. • Consumer interest in animal welfare increases demand for products using precision fermentation ingredients as 'freedom foods'. • Generally positive consumer perception of the commercialisation of alternative proteins. • Increased openness to consumption of alternative proteins, especially in Asia which is the destination for a large amount of NZ dairy products. This is driven to some extent by the use PFM in ingredients in processed food products — initially for low value products and with growing acceptance – increased use for higher value and B2C products.	• Generally positive consumer perception of the commercialisation of alternative proteins. • Improved quality, taste and texture lead to an increase in consumer demand for plant protein products. • Strong growth of markets for alternatives to milk proteins derived from plant products. • Sustainability is an important driver for consumer acceptance.	• Price parity is achieved for all alternative proteins. Some products are less expensive than animal based-proteins whilst still offering environmental benefits. • Taste and texture of alternative protein products improves significantly. • Heightened consumer interest in sustainable diets with increased consumer demand for plant and hybrid protein products. • Establishment of market for alternatives to milk proteins derived from plant products. • Very positive consumer perception of the commercialisation of alternative proteins. • Increased willingness to consume alternative proteins, especially in Asia which is the destination for a large amount of NZ dairy/meat products.

Scenario 1	Scenario 2	Scenario 3	Scenario 4
Regulatory trends			
• Regulatory restrictions on the sale of cellular protein products are persistent. • Trade barriers associated with the environmental impacts of animal products – e.g GHG – have limited impact on markets.	• Emergence of regulations and market access barriers/tariffs emerge for GHG emissions and other environmental impacts of animal-proteins. • Regulatory restrictions on PFM products reduced or eliminated. • Regulation of development and import of microbial strains and genetically modified organisms are relaxed/removed.	• No barriers to the production and consumption of plant protein products. • Regulatory restrictions on the sale of cellular protein products are removed slowly.	• Regulations and market access barriers/tariffs emerge for GHG emissions and other environmental impacts of animal-proteins. • Widespread taxation of GHG emissions from animal-based products. • Limited or no regulatory restrictions on the sale of emerging protein products.
Environmental trends			
• NZ regulatory policy around GHG, water quality, biodiversity result in a gradual decline in traditional pastoral production area, especially in marginal areas (i.e hill country). • Efficiency improvements in conventional agriculture compensate for changes in environmental condition without reducing global supply of animal proteins. • Full LCA analysis does not show a significant difference between animal and alternative proteins.	• Climate change, resource short-ages and biodiversity loss are source of increasing concern. • Emergence of robust policy and regulatory responses to manage these risks. • Energy efficiency improvements boost the sustainability claims of precision fermented ingredients.	• Decreased pollution (water) and GHG emissions due to land use changes from pastoral to arable and horticulture.	• Climate change, resource shortages and biodiversity loss have a high perceived impact. • Emergence of robust policy and regulatory responses to manage these risks.

5.3 Scenario criteria: Aotearoa/New Zealand context and impacts

The final set of criteria applied to each of the scenarios was the consideration of the context of protein (both traditional and alternative) production in Aotearoa/New Zealand. The former criteria sets largely addressed the global context for protein value chains and the position of animal-based and alternative proteins in global markets. These criteria helped to frame the expected response of both established animal-protein and emergent alternative protein production in Aotearoa/New Zealand, including potential regional variation based on relative exposure to market, regulatory and environmental pressures.

The New Zealand government incentives are included as incentives with the potential to impact on the protein sector and are not necessarily recommended or expected. They have been applied to demonstrate the potential for such incentives to encourage the distinct outcomes in the four scenarios. Similarly, the response of the New Zealand protein industry is not documented or recommended change, but changes that would reinforce or contribute to explaining the scenario outcomes. The land use impacts address the potential drivers from market and policy signals that would be expected to encourage participation in animal-based and alternative protein production, or the conversion to horticulture or forestry.

Table 8: Aotearoa/New Zealand context and impacts

Scenario 1	Scenario 2	Scenario 3	Scenario 4
NZ Government Incentives			
• Minimal incentives for the development of emerging proteins.	• Minimal incentives for the development of emerging proteins, with partial focus on precision fermented dairy products.	• Prioritisation of incentives for the development of the NZ plant proteins sector.	• Significant investment in precision fermentation and cellular products leading to a reduction in technical barriers. • Promotion of sustainable diets, and associated incentives for more efficient and productive protein production processes. • Possible incentives targeting plant-based serum for cultivated protein production, shift to plant proteins and plant-based milk.

Scenario 1	Scenario 2	Scenario 3	Scenario 4
Potential NZ land use impacts			
• Limited land use change from current pastoral production.	• Decreased demand for animal milk, affecting the income and viability of dairy farms. • Reduced farming intensity and production of milk in response to tariffs on GHG emissions. Impact would depend on market for 'natural' milk from animals. • Higher quality soils converted to horticulture/viticulture /urban land use.	• Increase in arable production to supply growing demand for plant proteins. • Commercial establishment of large-scale plant protein production (e.g., Leaft) provides opportunities for pasture/legume production.	• Reduction in dairy farming due to decreased demand for and value of milk in global markets. • Widespread taxation of GHG emissions from animal-based products. • Limited or no regulatory restrictions on the sale of emerging protein products.
Other impacts to NZ			
• Limited	• Decreased value in pastoral product exports. • Significant impacts to rural communities that are supported by pastoral farming.	• Ability to maintain production and export of milk substitute proteins depending on the competitiveness of plant proteins vs with those from precision fermentation.	• Decreased value in pastoral product exports. • Significant impacts to rural communities that are supported by pastoral farming.

Scenario 1	Scenario 2	Scenario 3	Scenario 4
NZ protein industry response			
• Business as usual in relation to the production and marketing of traditional meat/dairy products – however volumes are stagnant or declining due to decline in available land and impact of environmental regulations. • There is some development by traditional NZ protein companies of analogue products to enable the companies to grow overall production to meet increased global demand for protein and service their customer needs. • Some companies participate in domestic and export markets for plant proteins as ingredients.	• Some NZ protein companies develop capability for the production of precision fermented dairy products to complement their natural milk production (most likely occurring outside NZ closer to the markets and with distribution through the milk companies' value chains). • Some plant protein production to supplement milk proteins for the ingredient market requiring raw materials from NZ farmers.	• Increased production of some plant domestic plant protein products target local market with some limited exports. • Established animal protein companies develop and market plant protein products to complement their traditional product range e.g. 50/50 plant-based and meat products.	• Climate change, resource shortages and biodiversity loss have a high perceived impact. • Emergence of robust policy and regulatory responses to manage these risks.

6. Economic modelling

The economic modelling consisted of a staged process to first project the impacts of alternative protein taking up a larger proportion of the substitutable global protein markets and then to estimate the domestic environmental and land use impacts associated with scenarios which represents New Zealand entering into the supply of alternative proteins. The latter modelling was applied across relevant sectors) and included regionally specific results. Due to the relatively moderate contribution of alternative proteins in the expected growth in demand for protein in global food markets, significant changes in environmental and land use outcomes were not highly evident in the modelling to 2035. For the purposes of attaining useful data for a comparative assessment of the scenario outcomes, the land use and environmental modelling was extended to 2050. This extended timeframe did provide outcomes that better inform a discussion of possible policy recommendations. This section provides an explanation of the methodology for the modelling, including the structure of the models used. It also includes an overview of the outcomes that were used to inform policy recommendations.

6.1 Lincoln Trade and Environment Model (LTEM)

The model used in this research, the LTEM, is based upon VORSIM framework (Roningen, 1997). LTEM is a multi-country, multi-commodity partial equilibrium (PE) framework which focuses on the agricultural sector i.e. the linkages of the agricultural sector with the rest of the economy are not considered. The LTEM has been used to assess a number of international and national policy and trade decisions (Saunders & Cagatay, 2004; Saunders & Saunders, 2015; Saunders et al., 2016) highlighting the implications for NZ agricultural producers.

LTEM is used to quantify the price, supply, demand and net trade effects of trade and domestic agricultural support policies. The model is used to derive the long-term policy impact in a comparative static fashion. The included products are treated as homogenous and therefore perfectly substitutable in international markets. It is a non-spatial model in which the framework derives the net trade of each region, however, the supply and demand shares of countries in trade can also be traced. It allows the application of various domestic and border policies explicitly such as production quotas, set-aside policies, input and/or output related producer subsidies/taxes, consumer subsides/taxes, minimum prices, import tariffs and export subsidies—which, for the purposes of the Protein Futures NZ project are relevant to tariffs of other trade policies to regulate GHG emissions of foods. The economic welfare implications of policy changes are also calculated in the LTEM framework by using the producer and consumer surplus measures.

The LTEM framework includes 26 commodities and 22 countries. Among those relevant to protein production, the dairy sector is modelled as five commodities. Raw milk is defined as the farm gate product and then is allocated to either the liquid milk, butter, cheese, whole milk powder or skim milk powder markets depending upon their relative prices subject to physical constraints. The meat sector is disaggregated into sheep meat, beef, and pig meat in the current version of LTEM. Six crop products (wheat, maize, rice, sugar, coarse grains, oilseeds, oil meals, oil, apples and kiwifruit) as well as the poultry sector (poultry meat and eggs) and wool are also explicitly modelled in LTEM framework.

The general equation structure of each commodity at country level in LTEM framework is represented by six (eight for crops) behavioural equations and one economic identity[3]. The domestic supply and demand equations are specified as constant elasticity functions that incorporate both the own and cross-price effects. The model works by simulating the commodity-based world market clearing price on the domestic quantities and prices, which may or may not be under the effect of policy changes. Excess domestic supply or demand in each country spills over onto the world market to determine world prices. The world market clearing price is determined at the level that equilibrates the total demand and supply of each commodity in the world market.

LTEM modelling assumptions

The assumptions behind the LTEM scenarios quantified the changes in consumption by region and product type based on Morach et al. (2021). The projections in the Morach et al. paper covered until 2035. Logarithmic projects of the data from 2021–2035 were used to extend these projections until 2050 for the purposes of this research. Furthermore, as the projections in Morach et al. only addressed the segment of the protein market for which there were direct alternative protein replacements, the changes in consumption were scaled to the whole protein market in 2035. Feed stocks for the different alternative protein products were assumed as wheat; barley; maize; soybeans for 'plant protein'; raw sugar for 'micro-organism protein'; and the protein content of soybeans for 'animal cell-based protein'.

The scenarios that were modelled in the LTEM modelling are different from the scenarios that are modelled in the regional land use modeling. The scenarios that were used are described as follows:

Scenario 1 - Business as usual in LTEM trade model. No assumed uptake of alternative proteins

Scenario 2 - Assume alternative proteins have taken up 10% of substitutable protein market by 2035 and then a logarithmic projection of consumption which is based on Morach et al from 2035 to 2050.

Scenario 3 - Assume alternative proteins have taken up 11% of substitutable protein market by 2035 and then a logarithmic projection of consumption which is based on Morach et al from 2035 to 2050.

Scenario 4 - Assume alternative proteins have taken up 14% of substitutable protein market by 2035 and then a logarithmic projection of consumption which is based on Morach et al from 2035 to 2050.

Scenario 5 - Assume alternative proteins have taken up 22% of substitutable protein market by 2035 and then a logarithmic projection of consumption which is based on Morach et al from 2035 to 2050.

LTEM modelling results

The LTEM modelling of the five scenarios provided insight to the implications of different levels of alternative protein contribution to the global market for proteins. To some extent, especially for the 2035 time horizon, the impact of the alternative proteins was reduced by the expected increases in demand for proteins associated with global population growth through 2050 and

[3] Additional detail is available in Saunders (2023).

anticipated growth in the purchasing power with forecast economic growth. In the context of these assumptions, production of alternative proteins, as included in the four scenarios, is of a quantity to help meet the future demand for proteins, while not replacing production of traditional animal-based proteins in New Zealand.

The National level results of the LTEM modelling are shown in Table 9. What Table 9 shows is the price, supply, demand and net trade effects of trade and domestic agricultural support policies have the impact of diminishing the economic indicators at a National level as the percentage of the substitutable protein market taken up by alternative proteins rises from 10 % up to 22% while the environmental indicators all fall substantially as the percentage rises.

What we can assume from the LTEM modelling is that a small percentage of the substitutable protein market taken up by alternative proteins will have a negative effect on the National economic indicators while having a positive effect on the environmental indicators.

Table 9: The impact of the changes in the percentage of the substitutable protein market taken up by alternative proteins rises from 10 % up to 22%

	LTEM Scenario 1 Baseline Business as usual in the LTEM trade model. No assumed uptake of alternative proteins	LTEM Scenario 2 Assume alternative proteins have taken up 11% of substitutable protein market	LTEM Scenario 3 Assume alternative proteins have taken up 10% of substitutable protein market	LTEM Scenario 4 Assume alternative proteins have taken up 14% of substitutable protein market	LTEM Scenario 5 Assume alternative proteins have taken up 22% of substitutable protein market
Gross Output ($m)	53,926	-15,129	-14,720	-16,346	-19,513
Total Change for NZ economy ($m)	121,893	-32,495	-31,634	-35,054	-41,711
Employment (FTE)	392,186	-100,043	-97,455	-107,735	-127,759
Value Added ($m)	57,669	-15,848	-15,417	-17,128	-20,460
GHG Emissions (000t CO2e)	50,375	-10,932	-10,610	-11,961	-14,858
N Loss (t)	228110	-45,232	-44,217	-48,350	-57,295
P Loss (t)	18,363	-3,734	-3,655	-3,973	-4,659

What we believe is the key message from the LTEM modelling is that New Zealand production of proteins will not be immune from the negative effects of alternative proteins taking up a proportion of the substitutable proteins market and that the negative impact will be quite significant for all of the economic indicators. This means that New Zealand must develop a strategy that has us participating in the global alternative proteins market if we want to continue to grow our GDP while at the same time improving our nutrient loss and greenhouse gas emissions performance.

6.2 Regional land-use modelling

In addition to the global trade modelling, a regional level model of land-use change was developed for the project which was able to model the impact of a range of possible scenarios where the international trade in alternative proteins has an impact on the current land use in

New Zealand and some responses in terms of New Zealand joining into the production of alternative proteins.

An Excel-based tool designed to understand the production, environmental, and economic impact of land-use change for Aotearoa/New Zealand agriculture, given the future uptake of alternative proteins as proposed in the four scenarios was developed. In order to consider the land-use implications the four scenarios from The AgriBusiness Group projections (working with a 2050 time horizon) of New Zealand land use under different assumptions of uptake for the three categories of alternative protein were modelled.

The four scenarios modelled were:

Scenario 1 – Base case business as usual.

Scenario 2 - Plant Proteins 10%, Precision Fermentation 22%. Reduction in the dairy area by 35% reflecting the fact that NZ is dominant in world trade. Reduction in the dairy area occurs across lower production smaller farms former dairy farms revert to beef production. Assuming that a factory is built in New Zealand the arable area increases by 50% in Canterbury, Southland, Wairarapa and the Manawatu.

Scenario 3 - Plant Proteins 22%, Precision fermentation and Cellular 10%. Reduction in the dairy area by 15% which is modelled as occurring across lower production smaller farms which revert to beef production. The arable area doubles across all flat land which has been modelled as occurring mainly in the South Island with 25% converting from Dairy and 75% from Sheep and Beef. A reduction in the Sheep and Beef sector by 15% goes to Forestry.

Scenario 4 - Plant Proteins, Precision fermentation and Cellular all increase by 22%. Reduction in the dairy area by 35% reflecting the fact that NZ is dominant in world trade. Reduction in the dairy area across lower production smaller farms areas revert to beef production. Arable area doubles across all flat land mainly in the South Island with 25% from Dairy 75% from Sheep and Beef and the reduction in the Sheep and Beef sector by 25% goes to forestry.

The impact of each of these scenarios on the land use mix in New Zealand are shown in Table 10.

Table 10: Scenario 1 National land uses and the changes that occur as a result of the assumptions made across the remaining three scenarios.

	Scenario 1 No impact on current land	**Scenario 2** Precision fermentation for dairy ingredients becomes competitive	**Scenario 3** Plant-based products take off	**Scenario 4** Emerging proteins take off
Sheep	4,136,872	-123,597	-620,531	-1,219,613
Beef	2,692,132	601,632	-216,604	-133,199
Dairy	2,072,083	-725,229	-310,812	-725,229
Arable	494,387	247,194	494,387	370,790
Hort & Vegetable	126,329	0	0	0
Forestry	1,619,010	0	653,560	1,707,251
Total	**11,140,813**			

The disruption which is seen in Scenario 2 is a massive reduction in the Dairy area which converts to Beef and Arable and a much smaller reduction in the Sheep area which goes across to Arable.

Scenario 3 shows a lower reduction in the Dairy area which goes to Beef and the Arable area and a significant loss of area in the Sheep and Beef sectors which goes to Arable and Forestry.

Scenario 4 shows that the significant reduction in the Dairy area goes to Beef and a significant reduction in the Sheep and Beef sectors which goes across to the Arable and the Forestry sectors.

Note that there is no impact in the modelling as a result of the alternative protein scenarios on the Horticulture and Vegetable sectors because much of the production in this sector achieves financial returns which are above those of the other sectors, so they are not at risk of substitution and that much of the production in those sectors is not influenced by the protein market.

For the regional impact modelling, there are eight classes of agricultural land-use, with 20 associated production outputs. For each land-use class there is data by region for current land use (by hectares), production output (by commodity), financial data by hectare (revenue, farm working expenses, and Earnings Before Interest and Taxation (EBIT), and environmental outputs by hectare (nitrogen leaching, phosphorus losses, and greenhouse gas emissions).

The land-use change scenarios cause a change in the hectares allocated in each region across the various examined land-use classes. Using the scenario changes to land use (ha) by farm class and region, the outputs of production, revenue, and the associated changes to the environmental variables are given for each scenario. In the regional level, analysis stocking rates and output per hectare are assumed to be static between scenarios. No costs of transition are considered.

The regional land-use modelling also includes multiplier analysis for the whole economy impacts of land-use change. The multiplier analysis uses input output modelling to quantify the flow on impacts of changes in economic activity due to the land-use change scenarios.

‘Direct’ impacts are those associated with the changes in the examined industries (in this case the sub-sectors of the agriculture sector for which there are land-use changes). ‘Indirect’ impacts are the upstream and downstream effects in other industries due to the change in economic activity in the direct industries. This includes changes in spending on inputs and services used in agriculture and other sectors for which the agricultural sub-sectors might be an input. ‘Induced’ impacts are the increased or decreased impacts in economic activity implied from the income effects; changes to employment and thus spending associated with the direct and indirect impacts. In total, the multiplier analysis provides the economic impact for the whole of New Zealand’s economy of these changes in land-use and agricultural production. The multiplier analysis also provides these impacts in terms of changes in employment nationally given in Full Time Equivalents (FTE’s), and value added. Value added represents the total value of final goods i.e., without intermediate inputs. The multipliers used in the analysis are national-level multipliers, rather than specific to each region in the analysis.

In addition to the impacts on the national economy, the regional land-use modelling considered the impacts on the financial performance of specific productive sectors through the use of financial models. These models are essential to illustrate the impacts of the various scenarios outlined in the project. This aids in conceptualizing the financial viability of different farms in the given scenarios and broader national economic implications of them to the New Zealand economy.

Modelling results

The regional land use modelling results are reported at the National level and then an example of the difference impacts that occur at a regional level are discussed in terms of the impact of the modelled results on a region where the impacts are large, average and small.

National land-use modelling results

The results of the modeling at the National level are shown in Table 11: The changes that occur in the output measures for each scenario compared with Scenario 1.. The second column shows the output of Scenario 1 which is the Base Case business as usual. The subsequent columns show the changes that occur in the output measures for each scenario compared with Scenario 1.

Table 11: The changes that occur in the output measures for each scenario compared with Scenario 1.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	No impact on current land	Precision fermentation for dairy ingredients becomes competitive	Plant-based products take off	Emerging proteins take off
Gross Output ($m)	43,489	-4,007	2,457	1,366
Total Change for NZ economy ($m)	99,282	-7,994	6,951	6,727
Employment (FTE)	321,924	-22,584	22,486	18,410
Value Added ($m)	46,765	-4,267	2,616	1,771
GHG Emissions (000t CO2 e)	42,836	-5,615	-5,480	-11,999
N Loss (t)	193429	-11,427	-9,800	-33,451
P Loss (t)	15,427	-276	-736	-2,725

Things to note from Table 11 are:

The total amount of economic and environmental disruption that will occur in any of the scenarios is relatively small in the context of the total National output indicators.

Scenario 2 is the worst scenario in terms of economic impact with all of the economic indicators suffering negative impacts. This is because it indicates that the scenario models the impact of the loss of competitiveness of the Dairy industry with a small compensation of an increase in the arable industry resulting in negative economic performance.

Scenario 3 is about even in terms of the change in Gross Output and Value Added but it is a significant improvement in terms of the Total Change for the NZ economy and Employment while having satisfactory performance in terms of environmental indicators.

Scenario 4 is about even in terms of the change in Gross Output and Value Added but shows quite a change in the two indicators of Total Change for the NZ economy and Employment. Its performance in all of the environmental indicator's is quite spectacular because of the conversion of a large portion of previously agriculturally productive land into forestry.

In summary we can conclude that the impact of a substantial change in the National involvement in alternative proteins will be positive for the economic indicators and spectacularly positive for the environmental indicators.

However it should be noted that this modeling only incorporates the financial impact at the farm gate level. It hasn't considered the transition costs like the potential large losses in capital which will result from the change from a particular land use to another land use which has different

infrastructural requirements nor the loss of value of the processing and servicing sectors of those land use sectors.

Regional land-use modelling results

The regional land use results are particularly variable with some having large losses in terms of the economic indicators while having positive results in terms of the environmental indicators while other regions have significant gains in both economic and environmental indicators.

Here, the results from three regions (Canterbury, West Coast and Hawke's Bay) are presented to give an indication of the extent of change likely to be experienced, but also to demonstrate the level of variability across regions. These results are projected for 2050 from Scenarios 1 and 4 and are reported as economic and environmental output. Of the three regions, the modelling for Canterbury shows the greatest positive change in both economic (15% increase in Scenario 4 from Scenario 1) and environmental (38% decrease in GHG emissions, 15% in nitrogen and phosphorus loss) outcomes. These changes are largely the result of a shift in land-use from intensive dairying to arable crops. The West Coast, while a much smaller region in economic terms, presents a stark contrast with a negative change in economic outcomes (16% loss) and similar environmental impacts, albeit lesser benefits in terms of GHG emissions (24% decrease) and phosphorus loss (11%) and greater in terms of nitrogen loss (33%). The driver for these changes is again the diminishing viability of dairy, but with more limited options for conversion in the West Coast. Finally, the Hawke's Bay region shows a moderate growth in economic output (10%) and a decrease in GHG emissions (27%) more similar to the West Coast, in nitrogen loss (18%) more similar to Canterbury and a significantly higher decrease in phosphorus loss (22%). These results are driven to a greater extent by the falling viability of meat proteins, resulting (among other land-use changes) in conversion of hill country pastoral systems to forestry.

Table 12: Regional land use modelling example

	Canterbury	West Coast	Hawkes Bay
	Change from Scenario 1 to 4	Change from Scenario 1 to 4	Change from Scenario 1 to 4
Gross Output ($m)	1,436	-93	265
GHG Emissions (000 t CO2 e)	-2,763	-155	-490
N Loss (t)	-8,479	-1,917	-799
P Loss (t)	-514	-21	-204

These results reflect the greater sensitivity of the regional land-use modelling to the financial impacts of changes in production systems. It is also notable that the land-use potential of the regions impacts significantly on response to a larger increase in the contribution of alternative proteins to the global economy. This regional variation raises important issues for consideration of policy response.

7. Stakeholder interpretation and assessment of scenarios

The economic modelling incorporating the projections associated with each of the scenarios provides insight to the range of possible futures for existing protein production systems in Aotearoa New Zealand in light of the potential impacts of increasing alternative protein production. It must be acknowledged that the interpretation of the findings for policy recommendations is subject to the limitations of the economic assumptions that inform the modelling. Given the long time horizon, it is also very probable that unexpected factors will significantly change the social and economic environments associated with the development of protein production within the global agrifood system. In order to provide a more nuanced and locally relevant interpretation of the modelled outcomes, the implications of the scope and direction of change for Aotearoa/New Zealand was assessed using key informant interviews and an open online survey. Together these incorporate the iterative engagement features of the Delphi process, providing protein sector 'experts' the opportunity to comment on the analysis that emerged from the first interviews, as well as assessing the extent to which alternative proteins are a concern across the protein production sector.

7.1 Key informant interviews on modelled outcomes

The key informant interviews were developed with the purpose of identifying the perceived impacts of the modelled outcomes from diverse actors in protein production as well as a range of more pessimistic and optimistic expectations of the potential of alternative proteins. Fourteen participants (including rural professionals, industry representatives and researchers) were interviewed, selected from those who contributed to the first interviews in the project and known to have knowledge of alternative proteins. To collect a range of views, their relative level of optimism about alternative proteins was assessed based on their response in the first interview.

The national outcomes of the land-use modelling from the four scenarios provided the basis for the interviews (Figure 1). Because of this specific focus, the interviews employed a structured format ensuring that each informant had similar base levels of engagement with each of the scenarios presented during the interview. The participants were first asked to update their perceptions of the potential for alternative proteins as a significant element of global protein production. They were then asked to consider the outcomes of the modelling for each of the scenarios and to indicate whether such an outcome would be cause for concern or reason for optimism. Following the assessment of the scenarios, informants were also asked to comment on the extent to which the outcomes suggested a need for policy response as well as who would best take responsibility for such policy. This report provides an overview of the key findings from the interviews.

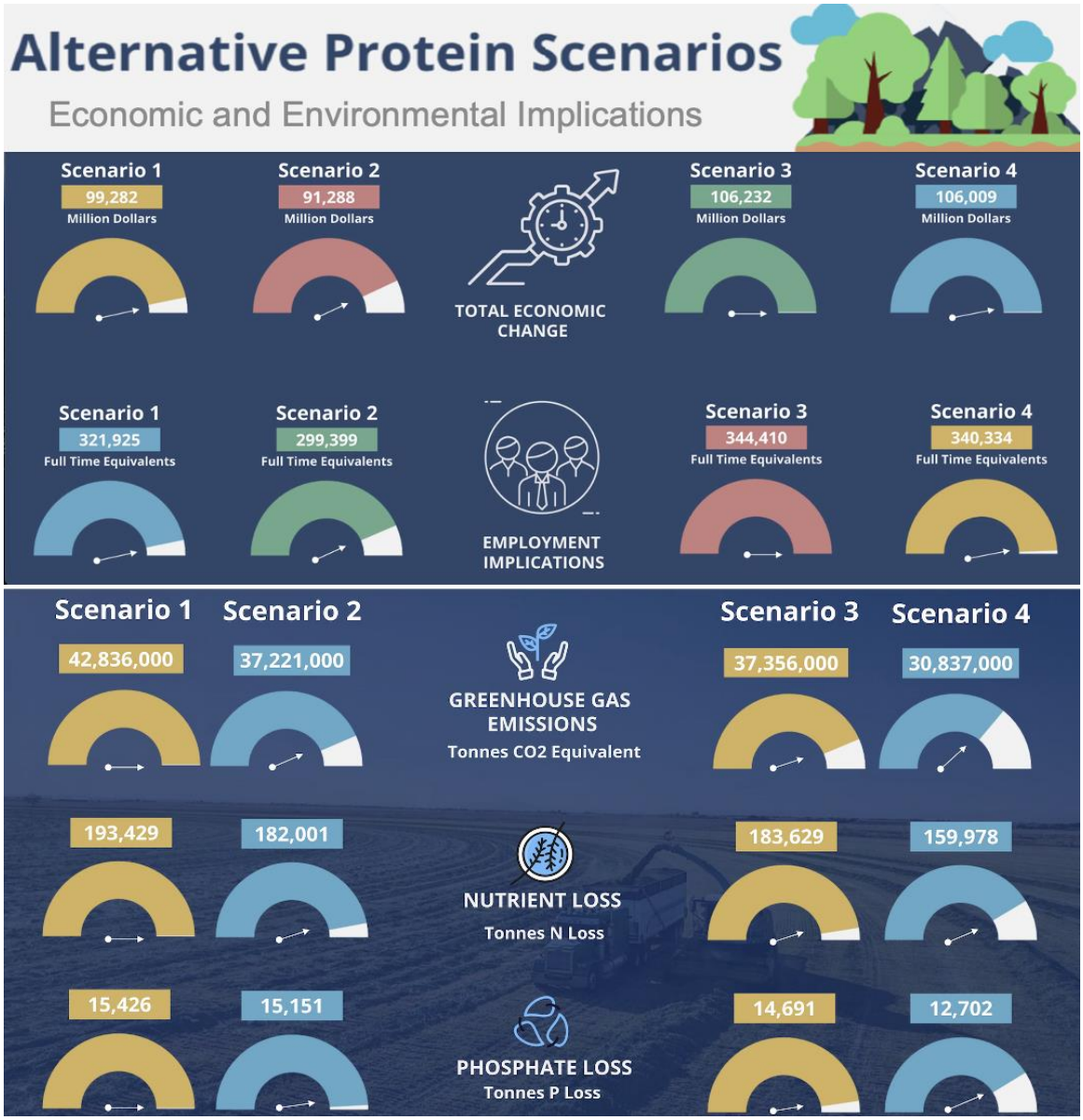

Figure 1: Scenario economic and environmental outcomes presented to interview participants

Change in Opinion

Interview participants were first asked whether their opinions on alternative proteins had changed since their previous interviews which were conducted 9 - 10 months ago. Their assessments of the potential impact of emerging proteins in New Zealand over the past nine months reveal diverse perspectives. While some respondents maintain optimism, citing recent achievements and alignment with governmental and industry trends, others stated concern about the impact on other industries. Some respondents highlighted slower than expected progress, resistance to ultra-processed foods and the importance of taste and texture to consumers. Other views outlined alternative proteins as a fad, citing market fluctuations and production issues.

Scenarios

There were a wide range of responses to the scenarios, all with their individual reasoning behind them. Some believe the scenarios underestimate the likely changes. Generally, these individuals were anticipating larger impacts due to factors like climate change and high prices for high-

emission products. Others were satisfied with the potential outcomes and range of scenarios presented. Some interviewees emphasized the likelihood of hybrid approaches in the alternative protein industry and suggested this as a consideration. Concerns were raised about government support, with uncertainties about New Zealand governmental stance. Some participants question the feasibility of scenarios due to the challenges in scalability, a lack of demand and comprehensive environmental analysis. When looking at specific elements, there were multiple interviewees who mentioned a lack of consideration for animal ethics in scenarios, outlining this as a motivation driver for some consumers. The interviewees had ranging opinions with the majority outlining that scenario 2 aligned closest with their expectations for global protein production. This didn't change greatly when asked about New Zealand specifically, however, many outlined New Zealand's lack of competitive advantage or suitability for some alternative proteins.

Figure 2 outlines that the interviewees all had varying opinions on the most likely outcome for global protein production and production within New Zealand. (Note that 2 interviewees did not select a specific scenario hence only 12 responses are reported).

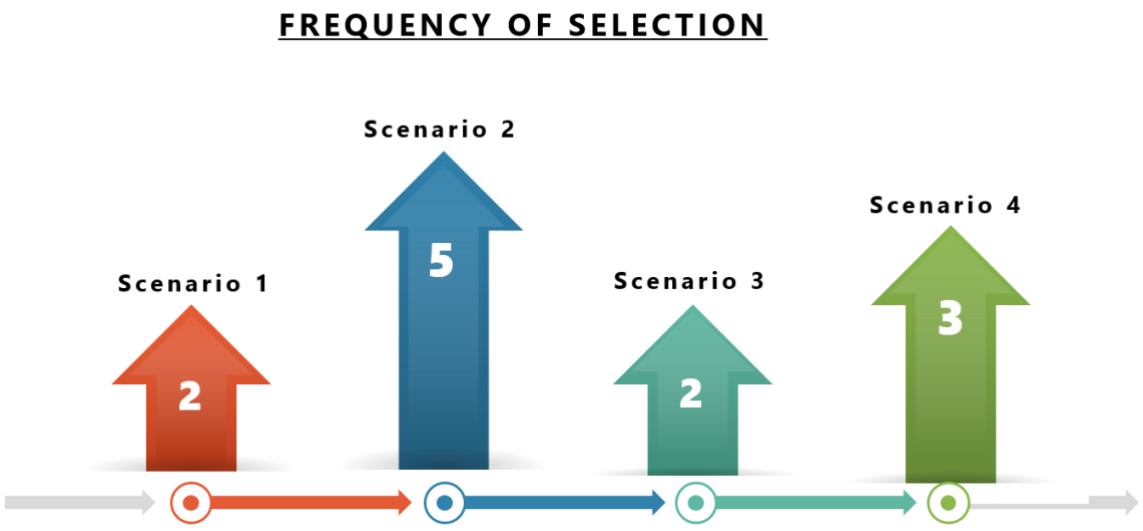

Figure 2: Relative frequency of choice of scenario

Modelling

Interviewees generally were in agreement with the modelling changes and found them representative of likely scenarios. Many outline that the economic changes between the scenarios are minimal in consideration of the scale of the industries. There were mixed views on the land use changes, many outlining that there is needed change in this area. Some, however, were sceptical of the scale of change that was modelled. A small proportion of others also stated that they thought the land use changes were too minimal and that animal product consumption may not be the usual in 2050.

The environmental impacts modelling was generally found as representative, however, there was some questioning around how the environmental impact of precision fermentation was modelled in the scenarios. Other concerns were raised about the growth in forestry, the profitability of arable farming, and the economic viability of changes, particularly in precision fermentation. The interviewees responses to the potential shift to alternative proteins in New Zealand showed an array of optimism and concern. While some express optimism about the country's ability to capture both traditional and emerging protein markets, others raise concerns about the negative consequences for existing industries and value advantage of alternative

proteins. Regulatory challenges were recognized as well as the importance of strategic diversification, effective marketing to highlight environmental and animal welfare benefits of alternative protein.

Policy

The majority of respondents outlined that a strategy or policy around alternative proteins would be beneficial with only a few respondents feeling that there isn't significant enough market pressure to call for any sort of policy response. These respondents outlined that market pressure should be the driver. Many of the interviewees detailed that the government needs to outline a position on alternative proteins but there also needs to be industry wide involvement. Some interviewees suggested that a national food strategy maybe the way forward or the creation of an agency like He Waka Eke Noa. Most of the policy suggestions were around incentivizing land use changes that create positive economic and environmental changes in the alternative protein space. Alternatives looked at aspects such as taxes on emissions or products that have a high environmental impact.

Overall, the attitude towards alternative proteins was positive, however most outlined potential challenges in creating products of value and identifying New Zealand's competitive advantage. Generally, most of the interviewees found the scenarios created were representative of potential outcomes, with the majority finding Scenario 2 most likely for global production. Animal welfare is something that the interviewees mentioned as a consideration that had not been factored into the scenario development.

The interviewees generally found the modelling representative, but concerns were raised about land use changes, precision fermentation impact, and the economic viability of proposed alterations. Most respondents advocated for a comprehensive strategy or policy for alternative proteins, suggesting collaboration between government and industry, with policy measures focused on incentivizing positive economic and environmental changes in the alternative protein space.

7.2 Survey response to modelled outcomes

Additional stakeholder feedback on the modelled outcomes was gathered through response to an online survey. The survey examined perceptions of the modelling outcomes as well as including questions on the need for policy and strategy. It was administered using the Survey Monkey platform and distributed through Our Land and Water, as well as being available on the Farmers Weekly website. Additionally, industry professionals chosen for their relevance in the field received personal invitations to participate.

As the objective was to assess the types of response that might be found among producers and processors of proteins in Aotearoa New Zealand, no effort was made to identify a random sample that could be used to suggest the representativeness of the response rate to the population. In other words, there is a strong potential that the frequency of specific responses to questions reflects the perspective of people more likely to respond to invitations to complete the survey extended through the Our Land and Water website, those who read Farmers' Weekly or those associated with animal protein industry groups. That said, the extent of similarity or contradiction between the survey response and the key informant interviews gives some insight to the whether the concerns and policy recommendations of the latter are shared with those 'at the coalface' of the protein sector.

The survey consisted of a short series of questions to organise response by the role of the respondent in the farm or enterprise and the sector to which the respondent associates. Survey participants were then presented with graphical representations of modelled outcomes with

brief explanatory text. (Given the limited extent of difference in the outcomes of Scenario 2 and 3 from the baseline Scenario 1, only Scenario 4 — that for the most optimistic projection of alternative protein development — was included in the survey to enhance the contrast for survey participants.) For each of the scenarios, they were asked to rate their level of optimism or concern and the desirability of the modelled outcomes for the protein sector and the environment using a Likert-scale response. This was followed by questions about the necessity of policy response associated with the impacts of alternative proteins.

Delivery of survey

The survey was open from October 18th to November 6th, providing respondents with a 20-day window to submit their responses. A total of 31 responses were received with most identifying as either rural professionals or 'other' (details on respondent background relative to the primary sector are provided in Table 13. Those in the other category (when identified) included researchers, conservation professionals and fertiliser distributers. The respondents also comprised a small portion of farmers, students, service providers and people with no rural background. Among the farmers surveyed (this included some respondents who had primarily identified as belonging to another group but also were involved in farming), there were four lifestyle farmers, three dairy farmers, and two horticultural farmers.

Table 13: Frequency of demographic response

Respondent category	Frequency
Rural Professional	10
Farmer/Grower	4
Rural Service Provider	1
No Rural Background	3
Student	1
Other	12
Total	31

Responses to Modelling

The survey asked the respondents to rate how they felt with regard to the economic and environmental impacts of the two scenarios presented (the results associated with Scenario 1 and 4). The respondents rated these impacts on a scale of 1 to 100, ranging from very negative to very positive. The response to the economic impacts show a substantially more positive response to the second of the two outcomes. This result is not overly surprising in that the economic output was higher. What may be of greater interest is the relatively low (less than 'neutral' at 50) assessment of the "business as usual" outcomes associated with Scenario 1. While much caution should be taken in interpreting these results due to the low number of responses (with several participants not providing a response to these questions) and the scattered distribution of response (noting the range and standard deviation in Table 14, they do suggest that the increasing presence of alternative proteins in the global market would be palatable for the primary sector in Aotearoa/New Zealand if it were accompanied by notable economic benefit. The information provided in the survey does not, however, allow for participants to consider that challenges involved in conversion from traditional, animal-based to other production systems.

Table 14: Distribution indicators for response to economic outcomes

Respondent category	Outcomes
Average	46/100
Range	86 (0-86)
Skewness	-0.08
Standard Deviation	23

Respondent category	Outcomes
Average	70/100
Range	51 (49-100)
Skewness	0.32
Standard Deviation	18

Table 14 provides insight to the pattern of responses to the economic outcomes of the regional land use modelling for the scenarios included in the survey. There were 18 valid responses to the economic outcomes modelled for the first scenario. The mean value of the Likert weighting of the relative desirability of the economic outcome was 46 (out of 100), indicating a combined neutral response. The negative skewness value of -0.08 reflects a slight skew towards the lower end of the distribution, although the deviation from symmetry is very minimal. Generally, the farmers and researchers ranked this outcome lower than the rural professionals, which may suggest the latter value the persistence of a "business as usual" context.

The standard deviation of 23 is sufficiently high to imply that the individual opinions are wide ranging and that expectations for the economic performance of the sector are inconsistent. There were a similar 18 responses to the economic outcomes for the second of the scenarios in the survey. Compared to the first scenario, the average score of 70 signifies a relatively positive response to the higher economic outcomes. These responses had a range of 51, which indicates a slightly tighter spread of values than for the first scenario. To some extent this may be the result of the single extreme rating of zero for the first of the scenarios. This is confirmed by the relatively lower standard deviation of 18, indicating a more moderate variability from the mean in the data points. A positive skewness value of 0.32 implies that the distribution is slightly skewed towards the higher end. This suggests that there the data points on the higher end of the distribution have a lower frequency (that is the scoring of 100 was 'isolated'), but this effect is not notably pronounced. There were no clear trends between the demographics causing them to rank higher or lower with a mixed response from all demographics presented.

The ranking of the environmental outcomes of the scenarios followed a similar pattern with the second of the scenarios receiving higher values. The overall enthusiasm for these outcomes was, however, lower than that given to the economic data. It is difficult to determine what underlies the lower scores, although it may reflect a current sense that environmental factors have received too much attention recently.

Table 15 provides detail on the distribution of the responses to environmental modelling. There were 16 responses to the environmental outcomes modelled for this scenario. The value of the assessments was 32 suggesting a somewhat negative response overall. This is reinforced by a range with a highest score of 51, which would be 'neutral' according to the scale used. The lower score of 3 is an outlier which is reflected in the negative skewness value of -0.36, suggesting a slight skew towards the lower end of the distribution and a higher frequency of data points on the higher end of the range.

The responses show a narrower spread of values, indicated by the range of 48, spanning from 3 to 51 and a standard deviation of 16. This indicates that the data points are more concentrated within this range compared to the economic modelling, suggesting a more consistent attitude toward environmental outcomes compared to the economic ones.

Notably, most of the higher rankings in this case (albeit still in the neutral or lower range) were given by participants who identified as rural professionals. A large proportion of these individuals ranked the outcome as neutral with 5 out of the 16 responses ranking the outcome at 50/100.

There was a greater number of responses for the second of the scenarios with 19 participants completing the question. The dataset is more similar to the rankings of the economic outcomes with a substantial range (82, spanning from 18 to 100) and higher standard deviation (25), indicating a wider dispersion of values across the dataset and many differing opinions on the environmental outcomes modelled. It is again difficult to determine the cause for this difference, although it may result from a lack of consistency in approving an environmental improvement that is linked to reduced production of animal-based proteins. That said, the overall response to the improved environmental outcomes (a mean value of 67, which is close to the higher approval value for the economic outcomes of this scenario, suggesting that the environmental outcomes could also influence interpretation of and subsequent response to a changing context of production that includes an increase in the role of alternative proteins in the global market.

Table 15: Distribution indicators for response to environmental outcomes

Respondent category	Outcomes
Average	32/100
Range	48 (3-51)
Skewness	-0.36
Standard Deviation	16

Respondent category	Outcomes
Average	67/100
Range	82 (18-100)
Skewness	-0.13
Standard Deviation	25

The survey results indicate that individual respondents are able to identify the positive outcomes achievable both economically and environmentally with a shift from the first to the second of the scenarios. This suggests that they might recognise the benefits associated with an increase in demand for alternative proteins. This was consistent for all of the roles associated with the sector, although there was little consistency of ranking within the categories.

The participants were also asked to assess the level or threat or opportunity (again using a Likert-scale response from 0, being very threatening, to 100, being very desirable) of the information provided in both modelled outcomes. In general, the average response of the participants equated to a neutral stance towards the impact of alternative proteins on themselves, rating their feelings at 58. The range in response was substantial, including high responses of 100 from a rural professional and 92 from someone involved in forestry and a low response of 4 from a horticultural farmer[4]. These extreme responses were not, however, representative of consistent higher or lower scores within the primary sector roles. Similarly, the results did not show strong concern over the implications of the findings for Aotearoa/ New Zealand, with an average rating of 60. The evaluation of impacts for the country was also highly variable with a range of 90 between the most and least positive responses (the extremes responses coming from the same individuals as in the response on personal impact).

Expectations on policy

[4] Comments from this farmer suggest that the response may be less an indication of the perceived threat of a future that included alternative proteins than of scepticism regarding the lack of benefit for the horticultural sector in the modelled outcomes.

A further objective of the survey was to evaluate the perceived significance of market shifts towards alternative proteins relative to other issues impacting on the primary sector, and if the respondents felt there is a need for policy around alternative proteins. The respondents were first asked to rank issues for the sector from most (1) to least (5) significant. The issues included were: Market shifts to alternative proteins; Animal welfare; Productivity; Climate Change; and Fresh Water Quality. Table 17 reports the respondents' ranking of market shifts to alternative proteins relative to the other issues.

This question was completed by 17 of the survey participants. As with other responses in the survey, there is a lack of consistency in the response, except for the ranking of climate change which was consistently either ranked first (10 responses), second (3) or third (3). A majority ranked shifts to alternative proteins as lowest or second lowest. For those ranking it second lowest, animal welfare was the issue considered to be of lesser significance. This suggests that most respondents were more concerned with environmental issues or the economic viability of current systems (in terms of productivity). It is, however, noteworthy that almost one-third of the respondents ranked alternative proteins as the most or second most (in both instances ranking after climate change) significant of the issues. The ranking of alternative proteins is interesting as it is the only issue of the five that is not currently impacting the sector. It is crucial to take into account the impact of the prevalence of issues with regard to current impacts, with topics like climate change and water quality consistently demanding attention as the target of potential regulation in the sector.

Table 16: Perceived need for strategy or policy in regard to alternative proteins

Need for strategy or policy	Percentage
Yes	82%
No	12%

Table 17: Ranking of significance comparison

Significance level	Frequency
1 Most significant	3
2	2
3	2
4	6
5 Least significant	4

The respondents were also asked whether the modelled impacts indicate a need for policy or strategy related to potential impacts of alternative proteins. The respondents stated strong support for the implementation of some type of policy or strategy with 82% agreeing that there is a need (see Table 16). This aligns closely with the second interviews in the Delphi process, in which the key informants also identified this need. Those individuals who did not see a need for policy or strategy were generally rural professionals, however this was not representative of this group as a whole. In a final policy-related question the respondents were asked who they thought should be involved in the development of policy and strategy. As indicated in Figure 3, the majority of respondents saw this as being a responsibility of both industry and government, with industry perceived to have the highest level and government a mixed high and moderate

level. The response also indicates an expected role for iwi, suggesting an awareness of the need for collaboration to get a positive result.

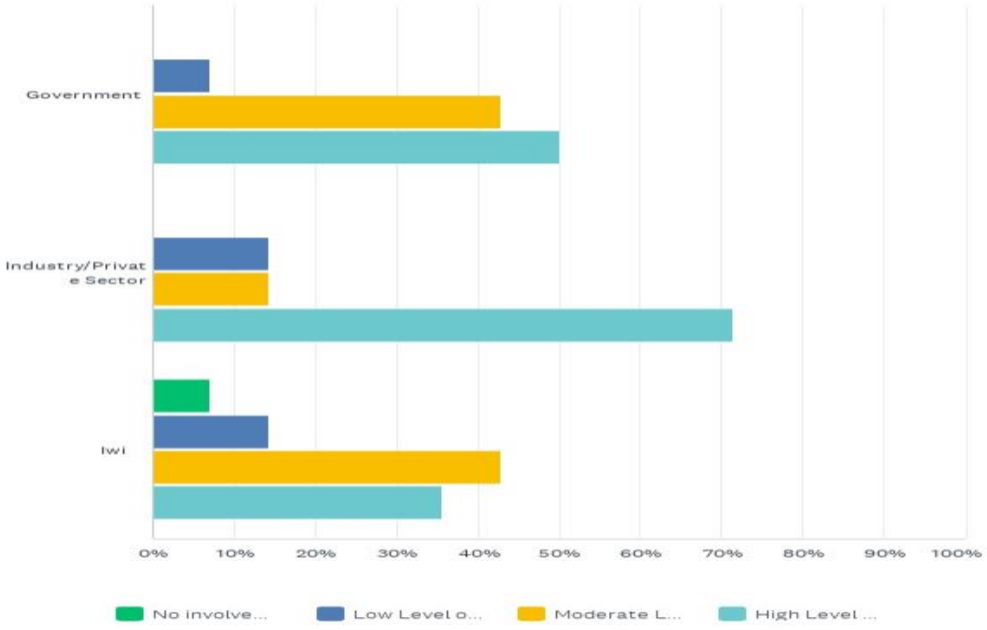

Figure 3: Who should be involved in the development of policy and strategy

Growth

The final question in the survey asked the respondents to reflect on the potential growth of alternative proteins with reference to variables likely to impact this growth. While a small number of respondents expressed the opinion that there would be no growth, most recognised the growth potential albeit at varying capacities. The majority of respondents expressed the belief that alternative proteins would contribute significantly to niche markets as opposed to having a more general impact on global protein markets. The ranking of the most likely variables to impact the uptake of alternative proteins resulted in the following average response:

1. Level of consumer demand
2. Comparative profitability to traditional protein production
3. Ability to scale up to commercial production
4. Development of innovations
5. Level of investment in alternative protein research

These results suggest that the respondents expect the influence of alternative proteins in global markets to be largely determined by consumer preferences and economic viability of these products, factors that are external to their own practices or control.

Conclusions

The key observation from the survey is that the perspectives expressed show a large range of opinions. Despite this variability, there does appear to be a general acceptance that alternative proteins will be, in some form, a feature of protein value chains in the future. The respondents were generally willing to acknowledge the positive outcomes associated with the shift from the first to the second of the scenarios presented, although the significance of these as a threat or opportunity was the source of high levels of variability. Although the most respondents did not

rank market shifts to alternative proteins as significant relative to environmental issues and productivity, a large majority supported the development of policy or strategy in relation to alternative proteins was necessary. The respondents expected that government and industry should have a high and iwi have a moderate level of involvement in policy development.

8. Policy Relevance

The outcomes of the Delphi process and the modelling of economic and environmental impacts of alternative proteins for Aotearoa/New Zealand require considered interpretation before being applied to a policy context. The main qualifier is that the actual performance of the alternative protein technologies remains in the realm of informed speculation. As is evident in the development of the scenarios used in this project, a multitude of factors (including the level of financial investment, the required advances in technology, the level of consumer acceptance, the adaptation of health and food safety regulations, the associated environmental impacts, etc.) will all independently impact on the future of the sector. The uncertainty around outcomes increases with modelling to a 2050 time horizon, a period over which these and currently unforeseen drivers will most likely not be consistent. This situation underlies the use of multiple scenarios in the project that allow the comparison of different futures—each of which reflects the prognostications of respected authorities in the development of technologies and markets associated with alternative proteins. The modelling, thus, does not indicate a certain estimate of future impacts; but it does provide insight to the degree and extent of the impacts that the primary sector can expect as alternative proteins establish a position in the global food system.

Despite the lack of a singular forecast of these impacts, consultation with experts indicates the need for policy to guide response—of both primary producers and protein processing industries—of stakeholders in Aotearoa/New Zealand. The expectation that policy will contribute to any response to the emerging role of alternative proteins is reinforced in the responses to the survey of reactions to the modelling outcomes in which respondents strongly supported the idea that there should be a considered policy process to manage the emergence of the sector.

In addressing the interpretation of the project's findings, our objective is to identify factors that should be considered in the development of policy originating in government and industry. In order to communicate these factors, we provide an assessment that highlights the strengths and weaknesses of current production systems, the opportunities for new forms of protein production/processing, and the threats and interactions with other drivers that are likely to influence exposure to and participation in alternative protein value chains.

Two policy considerations were central to the initial project proposal:

- evaluating opportunities to facilitate the development of more sustainable and resilient productive landscapes in Aotearoa New Zealand,
- providing guidance on the government and the private sector incentives for the alternative protein sector to maximise the opportunities and provide a guide for those engaged in the industry to realise that opportunity.

While these remain important, a further element for policymakers to consider — that became clearer as the project undertook research - is the potential for new proteins to create substitutionary threats to major primary production sectors, as well as potential benefits. What is more, interviewees for this project favoured a more considered process of policy formation to guide the potential direction of these protein sources. The associated technology should, therefore, be a subject of interest for policy deserving consideration by policymakers, industry and science institutions.

A second consideration is that this research project has been taking place alongside two parallel efforts to identify policy and development strategies for alternative proteins.

The MPI Food and Beverage: Draft Industry Transformation Plan (December 2022) laid out some clear options for creating both higher value-add to food and beverage products, but also to meet increasingly levels of environmental requirements. They specifically named alternative proteins (plant-based and artificially cultivated) as one area of promising development that needed to be supported by policy work to support transformation in four areas:

- Orienting the sectors towards consumers and the market
- Increasing investment in innovation and attracting capital for growth
- Building capability to innovate, commercialise and improve productive capacity
- Regulatory settings to enable food innovation.

As one of the key exemplars of 'emerging foods', alternative proteins were seen as needing policy interventions in all four of these areas, but particularly around attracting capital for growth and for overcoming challenges around scaling up and commercialisation.

This follows closely alongside the policy recommendations made by the FoodHQ report 'Unleashing Aotearoa New Zealand's Next Protein Revolution', which strongly recommended work to shift regulatory settings that might act as impediments to growth for promising start-ups developing alternative proteins. That report also provided abundant evidence for the addressing key deficits in science capacity and investments, as well as the need for a coordinated sectoral strategy.

In both of these reports, regulations around GMOs were identified as one area of constraint that could negatively influence some alternative protein technologies (while being influential on potential markets for other products that use a 'clean green GMO-free' branding).

Both these reports, along with other international literature and the modelling and Delphi results from this project identify the same 'sweet spot' around alternative proteins. This is that they have the potential to add value to primary production as well as to address major threats to primary production (for example, from climate change, changing market sentiments around things like animal welfare, and social challenges to the long-term viability of rural communities). Put simply, these products do have the potential to contribute to the formation of 'more sustainable and resilient productive landscapes'; but they will also challenge farmers and processors (of animal proteins, in particular) to adapt to new and uncertain market signals.

The following summary of the research undertaken in the current project reinforces this set of claims, but does also add in the opposite; that these new sources of protein have the potential to negatively disrupt our existing animal protein production systems. The latter effects have the potential to result in significant shifts in land ownership and disruption of rural livelihoods and regional economies.

These dynamics can be usefully examined using a SWOT analysis – seeking to situate the future scenarios for alternative proteins in the wider context of the needs, opportunities and strategic directions of the primary production sector in NZ. The emergent nature of alternative proteins and their contribution to global protein production and consumption makes the construction of a SWOT analysis somewhat problematic. The Delphi and literature analysis and its application to economic modelling failed to establish a particular preferable scenario, thus making it impossible to apply the SWOT analysis to a single desirable (or undesirable) future. Rather, we need to consider the overall primary production sector response across a variety of possible futures using a combination of the Delphi work, the modelling work, and the international literature review. The lack of knowledge of developments within the alternative protein sector by many actors also means that considerable input from the literature and individual experts on protein futures has been applied.

Strengths

As suggested by the LTEM modelling, the traditional animal-based protein sector in Aotearoa/New Zealand is well-placed to benefit from the forecast increase in demand for proteins globally. To the extent that demand for a 'natural' or more 'traditional' form of protein outweighs concerns over the environmental and animal welfare impacts of animal proteins, there should be opportunity to export meat and dairy. The global demand for protein will likely crate a space for alternative protein production to complement, rather than replace, animal proteins.

Aotearoa/New Zealand has a strong reputation for naturalness. As a key problem for alternative proteins is that consumers perceive them to be 'unnatural', the country's position could be leveraged to market alternative production, thereby negating the geographical disadvantages of location to some extent.

An alternative protein industry in Aotearoa/New Zealand could exploit the readily available and cheap renewable energy (with limited competing demand). Such energy is a key requirement to ensure the sustainability of fermented and cellular proteins, leaving the country with a strong basis to compete in environmentally aware markets.

In combination with available renewable energy, Aotearoa/New Zealand is in a strong geopolitical position to attract investment into the alternative protein sector. While areas such as North Africa have the potential to provide significant amounts of solar energy (with, for example, the UAE currently building a dedicated PF milk protein factory), they may lack the political stability.

New Zealand's expertise in marketing dairy proteins as ingredients can be leveraged to promote the development of a precision fermented dairy sector. This could further benefit from existing expertise in the installation, use and maintenance of fermentation tanks in the country's wine and beer industries.

Some of Aotearoa/New Zealand's traditional protein suppliers have been amongst the early innovators in the sector. For example, Fonterra now has investments in two start-up companies working on milk proteins (Motif and X). Investors in Synlait are also investing in production of plant proteins through Leaft Foods.

There is an established research infrastructure for alternative proteins in Aotearoa/New Zealand. In particular, there has been some development of infrastructure to support alternative proteins (e.g. Riddet Institute) as well as two precision fermentation start-ups in the country.

Weaknesses

Many of Aotearoa/New Zealand's geographical advantages are negated by cultivated proteins. For example, with cultivated protein it is possible to produce fresh fish in a desert. The country's current climatic and topographical advantages are negated by cultivated proteins, as are any seasonal advantages of providing fresh produce for the Northern Hemisphere winter.

An established reliance on the dairy sector and on bulk protein exports makes Aotearoa/New Zealand particularly vulnerable to the development of precision fermentation factories producing milk proteins and fats.

Alternative protein technologies are more adaptive to market conditions. Even if Aotearoa/New Zealand's agricultural sector is able to compete on price, any change in production (e.g. from beef to lamb) requires substantial restructuring of the primary sector taking years or decades. However, bioreactors can be repurposed to produce different products in a matter of weeks.

Private investment in alternative proteins in Aotearoa/New Zealand has been relatively weak in the early stages. While there have been notable investments in the sector (e.g. Fonterra), out of 480 (2011–2022) investments in early start-ups (2011-2018) globally in the precision fermentation and cultivated meat sectors registered in Crunchbase, only one investment was from an investor registered in the country: Aera VC invested in a seed round for the pet food Wild Earth in 2018. (Source: Authors).

Opportunities

The complementary nature of alternative proteins for traditional animal-based ones can strengthen the primary sector and protein value chains more generally. In particular, the potential undersupply of animal proteins in the future may require the addition of alternative proteins to ensure food security, grow the protein sector, and maintain the processing sector (as noted by a respondent in the Delphi study).

As is evident from the case of vanilla (Burton, 2019), where substitutes are introduced that are not identical to the substituted product, a bifurcation of the sector emerges of a high value natural product sector and a low value artificial sector. Specific targeting of the high value natural sector so as not to compete with artificial substitutes could provide significant opportunities. This would require an emphasis on extensive and natural forms of production as opposed to intensive industrial livestock production.

Efforts in overseas markets to reduce GHG emissions through subsidies placed on the basis of CO2e/kg protein (see Threats) would create an opportunity for Aotearoa/New Zealand's primary sector to supply a high value natural meat market.

There will be opportunities to provide food for cell-based protein production. The race to find the best serum for cell growth (which may be specific to an animal species) creates an opportunity to establish a feed stock industry if IP rights can be obtained. It also provides the potential for bioprospecting of the country's native species and to benefit Māori interests.

For plant-based proteins there is some opportunity to produce legumes for the sector. However, this seems unlikely to be a particularly lucrative industry in comparison to developing service products (e.g. serum to feed cells) for the precision fermentation or cultivated protein sectors.

Threats

Strong action to mitigate climate change through reduced GHG emissions may involve countries switching from the subsidising of agriculture to the subsidising of protein production on the basis of CO2e/kg protein. Current analysis indicates that the alternative protein sector receives substantially less subsidy and public investment than animal proteins (according to Vallone & Lambin, 2023, plant-based proteins received less than 0.1% of the public funding for meat and dairy in the USA and EU). While the removal of agricultural subsidies would advantage Aotearoa/New Zealand's unsubsidised agriculture, the switch to subsidising on the basis of GHG emissions could introduce substantially higher subsidies for and investment in alternative proteins — dramatically increasing its competitiveness and market threat.

The use of tariffs on imports with high GHG emission profiles could require the primary sector in Aotearoa/New Zealand to face competitive challenges from alternative proteins. As final dates to meet climate change obligations approach, pressure on countries to significantly decrease emissions form agriculture will increase. While a move to alternative proteins will decrease the availability of natural proteins on the market, again, the introduction of tariffs for natural proteins could create difficulties for New Zealand exporters.

Regulatory change in overseas countries poses a potential threat to exports from Aotearoa/New Zealand. China, the country's main dairy market, is proposing to promote the development of precision fermentation dairy products, including "future foods" as a solution for food security in its recent 5-year plan. As part of its response to market conditions created by Brexit, the UK government is planning to open its regulatory system to the entrance of alternative foods.

An additional pandemic of a zoonotic disease would provide strong pressures to move towards less industrial forms of animal production. Zoonotic disease transfer cannot occur with plant-based, precision fermentation, or cellular alternatives, meaning alternative proteins may be considered a safer option for human protein consumption in a more densely populated world. Food scares such as BSE may also lead public opinion to move towards alternative proteins.

Significant market fluctuations will have less of an impact on the alternative than the conventional protein sector. Natural production is infrastructure dependent such that with a long-term decline in market value of the commodity it is not possible to maintain the system without significant social and economic loss. However, bioreactors can be rapidly repurposed or placed in storage.

While natural production of animal proteins has been refined for millennia, precision fermentation and cell-based animal proteins are relatively recent technologies – as are the extrusion plant-proteins. Being at a very early stage of scientific development, there is greater potential for rapid development and advancement. Thus, while efficiencies can be improved in both protein sectors, it is likely to be alternative rather than conventional protein production that improves more rapidly in the short-term.

The incremental development of scientific knowledge is irreversible. Thus, even if progress in precision fermentation or cell-based protein development is halted as a result of lack of funding (as occurred to some extent as a result of interest rate rises after the Russian invasion of Ukraine) or hits seemingly insurmountable technical obstacles, the threat to conventional animal proteins will never be absent. Conventional agriculture needs to be continually looking over its shoulder and adjusting itself accordingly.

The advent of larger and more effective bioreactors currently under development could see the cost of precision fermentation proteins decline significantly and undercut animal protein cost while the product itself (e.g. whey powder) can be easily substituted in commercial production without requiring the retooling of production facilities. As the development of commercially viable cultivated meat is still uncertain and plant-based meat is not a direct substitute for animal protein, it seems the meat sector is under less immediate threat than dairy.

Policy observations

First, conventional agriculture needs to play increasing consideration to reduction of GHGs. Whether to meet the country's Nationally Determined Contribution under the Paris Agreement or to mitigate the impact of attempts to introduce low GHG alternative proteins in export markets, the potential for significant impacts on the primary sector will be significantly higher if carbon reductions are not made.

Second, there is a potential 'feed industry' emerging that NZ could engage in. Whether in the form of serum for cell-based products or improved media for yeasts used in PF production, any major transition to these protein sources will require a massive supply of high quality feed. This involves establishing both scientific research into the area and potentially bioprospecting for new materials amongst NZs native fauna. The bulk supply of plant protein for plant-based meats and milks is less likely to be profitable.

Third, New Zealand needs to prepare for a significant restructuring of markets. A key impact of the new technologies is that countries previously dependent on imports (e.g. China, Israel, UK, Singapore) will be able to produce their own animal proteins. As a result, countries dependent on animal protein exports could be particularly hard hit.

Fourth, the likely bifurcation of the animal protein sector into high quality 'natural' products and low quality 'artificial' products (e.g. vanilla and vanillin) suggests NZ needs to maintain more extensive and natural forms of production as a key strategy for future development. The worst case scenario (not modelled) involves a general sectoral move to highly intensive production simultaneous to the arrival of bulk cheap artificial proteins against which it is unable to compete. The inability of conventional agriculture to rapidly restructure itself as a result of fixed infrastructure costs makes heavy investment in highly intensive production over the next decades a risky strategy.

Fifth, NZ needs to look particularly at the dairy sector. In addition to the growing trend for plant-based milk the threat to NZ is currently much higher from PF dairy proteins than it is from cultivated meat or even plant-based meats. The commercial production of whey is already established while casein and milk fats can also be produced (but are not yet in commercial production). Fonterra's response of engaging with the sector appears prudent.

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